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INVESTIGATION OF SELECTED POTENTIAL ENVIRONMENTAL CONTAMINANTS: HALOALKYL PHOSPHATES

August 1976

FINAL REPORT

Office of Toxic Substances
U.S. Environmental Protection Agency
Washington, D.C. 20460

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ABSTRACT

This report reviews the potential environmental hazard from the commercial use of haloalkyl phosphates (HAP). Emphasis is placed mostly on the four tris(haloalkyl) phosphates which are used as fire retardants. Data on the two pesticide HAP's, naled and dichlorvos, are used for comparison purposes. The tris-HAP's (1) are produced in significant quantities, (2) have several potential sources of environmental contamination, (3) have an unknown fate in the environment, (4) may act as cholinesterase inhibitors, and (5) are potentially carcinogenic and mutagenic.

17 KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
naled, dichlorvos tris(2-chloroethyl) phosphate tris(2-chloro-1-propyl) phosphate tris(1,3-dichloro-2-propyl) phosphate tris(2,3-dibromo-1-propyl) phosphate organophosphates toxicity , fire retardants		

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INVESTIGATION OF SELECTED POTENTIAL ENVIRONMENTAL CONTAMINANTS:

HALOALKYL PHOSPHATES

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August 1976

Final Report

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Executive Summary

Haloalkyl phosphate compounds are used as pesticides and fire retardants. The four tris(haloalkyl) phosphate fire retardants, which are reviewed in detail in this report, are produced and consumed in the United States in approximately 30 million pounds per year. The three tris(chloroalkyl) phosphates are used mostly in polyurethane foams which are additives in products which must meet state or Federal fire retardancy standards (e.g., furniture, automotive parts, and household goods). The single tris(bromoalkyl) phosphate compound is consumed almost exclusively as a fire retardant additive for cellulose acetate and polyester fibers in textiles. Loss to the environment from production and consumption of tris(haloalkyl) phosphate fire retardants is unknown; there is some evidence that the tris(bromoalkyl) phosphate may be washed from textiles during home laundering and it is also possible that the other tris(haloalkyl) phosphates are eventually released from the materials in which they are incorporated. One of the tris(chloroalkyl) phosphates appears on EPA's list of organic chemicals detected in drinking water.

The environmental fate of the tris(haloalkyl) phosphates is unknown; entry into and transport through the aquatic media, however, appear to be the most likely sources of contamination. In one study, the tris(bromoalkyl) phosphate produced 100% mortality in goldfish at 1 ppm in water. The major health effects areas of concern for the haloalkyl phosphates are related to their potential for cholinesterase inhibition and their potential for biological alkylation. The tris(haloalkyl) phosphates may not be potent inhibitors of cholinesterase enzymes since they are much less acutely toxic to mammals than the insecticidal haloalkyl phosphates, which possess strong anticholinesterase activity. However, the anticholinesterase activity of the tris(haloalkyl) phosphates has not been studied in detail. In one study, the tris(bromoalkyl) phosphate has produced cholinesterase inhibition and severe toxicity in fish.

Perhaps of greatest concern is the potential for mutagenic and carcinogenic activity of the tris(haloalkyl) phosphates which may possibly result from alkylation of biologically important molecules. Such activity seems possible based upon known chemical and physical properties of the tris(haloalkyl) phosphates, although it has not been demonstrated experimentally in biological systems. Biological alkylations are often correlated with the production of both carcinogenic and mutagenic responses. Experimental evidence has shown that the tris(bromoalkyl) phosphate causes mutations in certain bacterial systems. Further studies on mutagenesis and the induction of cancer in mammals by this substance are in progress.

In summary, the tris(haloalkyl) phosphates:

(1) are produced in significant quantities
(2) have several potential sources of environmental contamination
(3) have an unknown fate in the environment
(4) may act as cholinesterase inhibitors
(5) are potentially carcinogenic and mutagenic.

Therefore, considerable experimental information must be generated before an adequate and reliable assessment of environmental hazard for haloalkyl phosphates is possible.

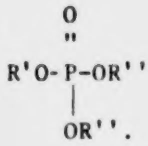
The positive results of the tris(bromoalkyl) phosphate as a mutagen in bacterial systems is particularly significant because of the potential for direct human exposure. A major application for the compound is as a fire retardant in children's sleepwear, which presents the potential for both oral and dermal exposure. The Environmental Defense Fund has recently petitioned the Consumer Product Safety Commission concerning regulation of the application.

I. Physical and Chemical Properties

A. Structure and Properties

1. Chemical Structure

Haloalkyl phosphates are triesters of phosphoric acid that have the general formula:



$$R'O-\overset{\overset{\displaystyle O}{\|}}{P}-OR''' \quad \text{with } OR'' \text{ on P}$$

R', R'', and R''' are alkyl groups, and at least one must contain one or more halogen atoms. The haloalkyl phosphates are either fire retardants or pesticides. Although more technical information is available on the pesticides, emphasis in this report has been placed upon the fire retardants. Whenever possible, analogies are drawn between information on the pesticides and fire retardants, especially when data are unavailable for the fire retardants.

Table 1 summarizes the names and structural formulas of the six haloalkyl phosphates selected for study. They are usually named as esters of phosphoric acid. Since these names are rather tedious, common names or acronyms will be used in this report. Four of the six haloalkyl phosphates are used primarily as fire retardants, and two are insecticides. The fire retardants are DBPP [tris(2,3-dibromopropyl) phosphate]; CEP [tris(2-chloroethyl) phosphate]; CPP [tris(2-chloropropyl) phosphate] and DCPP [tris(1,3-dichloroisopropyl) phosphate]. The two insecticides are dichlorvos [dimethyl 2,2-dichlorovinyl phosphate] and naled [dimethyl 1,2-dibromo-2,2-dichloroethyl phosphate].

Table 1. Nomenclature of the Selected Haloalkyl Phosphates (Kosolapoff, 1950; Frear, 1965; Spencer, 1968; Stauffer Chemical Co., undated a,b,c,d)

Name or Acronym Used in Text	Name	Synonyms and Trade Names	Structural Formula
DBPP	Tris(2,3-dibromo-1-propyl) phosphate	Tris(2,3-dibromopropyl) phosphate 2,3-Dibromo-1-propanol phosphate Firemaster T23P Fyrol HB32, Fyrol 32B Great Lakes TP-69 Nuogard 23P	$(BrCH_2CHBrCH_2O)_3P{=}O$
CEP	Tris(2-chloroethyl) phosphate	Tris(β-chloroethyl) phosphate 2-Chloroethanol phosphate FYROL CEF	$(ClCH_2CH_2O)_3P{=}O$
CPP	Tris(2-chloro-1-propyl) phosphate	Tris(2-chloropropyl) phosphate 2-Chloro-1-propanol phosphate FYROL PCF	$(CH_3CHClCH_2O)_3P{=}O$
DCPP	Tris(1,3-dichloro-2-propyl) phosphate	Tris(1,3-dichloroisopropyl) phosphate 1,3-Dichloro-2-propanol phosphate FYROL FR-2	$[(ClCH_2)_2CHO]_3P{=}O$
Dichlorvos	2,2-Dichlorovinyl dimethyl phosphate	O-2,2-Dichlorovinyl O,O-dimethyl phosphate, 2,2-Dichloroethenyl dimethyl phosphate, DDVP, Vapona, Nogos, Nuvan, Dichlorphos, Vinylophos, Chlorvinphos	$(CCl_2{=}CHO)(CH_3O)_2P{=}O$
Naled	1,2-Dibromo-2,2-dichloroethyl dimethyl phosphate	O-(1,2-Dibromo-2,2-dichloroethyl)O,O-dimethyl phosphate, Dibrom, Dibromfos	$(CCl_2BrCHBrO)(CH_3O)_2P{=}O$

2. Physical Properties

The general physical properties of the selected haloalkyl phosphates are summarized in Table 2. The data were gathered from listings of properties for commercial products as well as for purified materials. No physical property data for pure DBPP or DCPP were found in the literature. Where values are taken for commercial products, they are for the purest grade. All have relatively low vapor pressures, high boiling points, and high densities.

The commercially-available fire retardants are characterized as essentially odorless liquids ranging in color from colorless to pale yellow. The commercial pesticides are described as possessing some odor and being essentially colorless to pale yellow or straw color.

As commercially-available products, all the selected haloalkyl phosphates are viscous liquids at ambient temperatures. The viscosities are important in handling the fire retardants and for some, the temperature must be increased to permit their pumping in conventional manufacturing technology (See page 72). Figure 1 depicts the temperature-viscosity relationship for DBPP.

Solubilities of the selected haloalkyl phosphates are summarized in Table 3. Solubility of the esters in water and water in the esters decreases with increasing molecular weight. The insecticides are somewhat soluble in aliphatic hydrocarbons, but the chloroalkyl phosphate fire retardants are characterized as insoluble. The esters are soluble in aromatic hydrocarbons and in a wide range of chlorinated and oxygenated organic solvents.

Table 2. Physical Properties of Selected Haloalkyl Phosphates (Kosolapoff, 1950; Cherbuliez, 1973; Southwest Research Institute, 1964; Chevron Chemical Co., 1970; Shell Chemical Co., 1973a; Stauffer Chemical Co., undated a,b,c,d, 1972a,b, 1973a,b,c; Great Lakes Chemical Corp., 1973a, b; Michigan Chemical Corp., 1962, 1974 b; Frear, 1965; Spencer, 1968)

Haloalkyl Phosphate	DBPP	CEP	CPP	DCPP	Dichlorvos	Naled
Empirical Formula	$C_9H_{15}Br_6O_4P$	$C_6H_{12}Cl_3O_4P$	$C_9H_{18}Cl_3O_4P$	$C_9H_{15}Cl_6O_4P$	$C_4H_7Cl_2O_4P$	$C_4H_7Br_2Cl_2O_4P$
Molecular Weight	697.7	286	327.7	430.9	221.0	381
Weight Percent Bromine	68.7					
" " Chlorine		36.7	32.5	49.1		
" " Phosphorus	4.4	10.8	9.5	7.2		
Refractive Index n_D		1.4731 (20°C)	1.4625 (25°C)	1.5022 (20°C)	1.4541 (20°C)	1.5108(28°C)
Melting Point, °C				27		26.5-27.5
Freezing Point, °C	5.5	-20		26		27
Pour Point, °C	-1.16	-41.1	< -40			
Viscosity, centipoise	9200 (25°C)	42.9 (20°C)	78 (20°C)	2900 (20°C)		
Boiling Point, °C		145 (0.5 mmHg) 180 (5 mmHg) 194 (10 mmHg)		236-7 (5 mmHg) 248 (10 mmHg)	77 (1 mmHg) 120 (14 mmHg)	110 (0.5 mmHg)
Vapor Pressure, mmHg	0.19×10^{-3} (25°C) 1.2×10^{-3} (45°C) 4.8×10^{-3} (65°C)	0.5 (145°C)		0.01 (30°C) 0.1 (60°C)	0.032 (32°C) 0.290 (60°C)	2×10^{-4} (20°C)
Density, g/ml	2.27 (25°C)	1.4256^{20}_{4}	1.290^{20}_{20}	1.5182^{20}_{4}	1.415^{20}_{4}	$1.965\text{-}1.972^{20}_{20}$
" lbs/gallon	18.9 (25°C)	11.85 (68°F)	10.8 (60°F)	12.60		
Surface Tension dynes/cm (20°C)				43.83		
Coefficient of Expansion $10^4/C°$		7.7			4.2	
Physical Description of the Commercial Material at Ambient Temperature	pale amber to light yellow, viscous liquid	clear, pale liquid	clear, transparent liquid	clear, pale, viscous liquid	clear and colorless to amber liquid	pale, straw colored liquid; if purified, it is a white solid
Odor of Commercial Product	None	None	None	None	Mild	Pungent

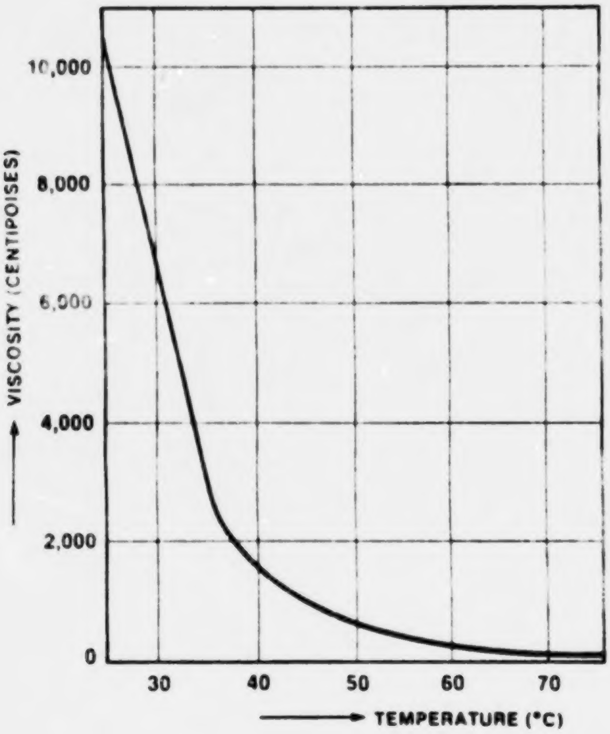


Figure 1. Temperature-Viscosity Relationship for Firemaster LV-T23P (DBPP) (Michigan Chemical Corp., 1974b)

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Based upon the solubility properties of DBPP, McGeehan and Maddock (1975) concluded that it is an excellent choice for fabrics which are to be laundered but not dry cleaned. If a DBPP-treated fabric requires dry cleaning, a hydrocarbon solvent should be used instead of the common, commercial chlorinated hydrocarbon dry cleaning solvents. Judging from the listed solubility data, the above conclusion may also be extended to CEP, CPP and DCPP. Information on the losses of DBPP from the laundering of treated fabrics is discussed in Section II-C, p. 63.

Physical properties of haloalkyl phosphate fire retardants must conform to the requirements of the materials to which they are added.

Table 3. Solubilities of Selected Haloalkyl Phosphates (Gunther *et al.*, 1968; Stauffer Chemical Co., undated a,b,c,d; Michigan Chemical Corp., 1974b; Kerst, 1974)

	DBPP	CEP	CPP	DCPP	Dichlorvos	Naled
Water in haloalkyl phosphate (by weight)[a]		5.4%	1.5%	0.30%		
Haloalkyl phosphate in water (by weight)[a]	0.0002%	0.7%	0.11%	0.01% (30°C)	1%	very Sl S
Aliphatic hydrocarbons	I	I	I		[illegible]	Sl S
Aromatic hydrocarbons	S	S	S		S	S
Halogenated hydrocarbons			S			
Methylene chloride	S				S	
Chloroform	S	S				
Carbon tetrachloride	S	S		[illegible]		
Perchloroethylene		3%		[illegible]		
Fluorotrichloromethane	I			[illegible]		
Norgechlor 811		6%				
Oxygenated organic solvents			S			
Alcohols		S				
Methanol	S			[illegible]		
Glycols				I	1%	
Ethers		S				
Glycol ethers		S				
Esters (Ethyl acetate)	S					
Ketones (Acetone)	S	S				
Dimethyl formamide	S					

Sl S - slightly soluble
S - soluble
I - insoluble

a. Percentages are at ambient temperatures

In plastics applications, desirable properties include compatibility with the resin, thermal stability, and low volatility. Haloalkyl phosphates are incorporated as external additives into resins. External additives, which are not chemically bound to the resin, can leach, exude, or otherwise migrate from the formulated product. The compatibility of an additive in a resin is related to the ability of the resin to retain the additive. Darby and Sears (1968) define compatibility as the ability of a resin and a plasticizer to be blended intimately into a homogeneous mixture with useful plastic properties. Table 4 lists the compatibility of three of the flame retardant haloalkyl phosphates with a number of commercially important resins.

The incompatibility of dichlorvos and polyvinyl chloride is taken advantage of in the dichlorvos resin strip (Shell Chemical "No-Pest Strip"). Dichlorvos is chemically stable within the resin, but will exude at a sufficient rate to maintain an insecticidally toxic atmosphere for several weeks (Darby and Sears, 1968).

Thermoset plastics require that any additives that are used be capable of withstanding the processing temperatures (Howarth et al., 1973; Darby and Sears, 1968). Although haloalkyl phosphate flame retardants are not very thermally stable (Tables 5 and 6), DBPP and DCPP are sufficiently stable for use in some thermoset plastics (Howarth et al., 1973; Darby and Sears, 1968).

Low volatility of a plastic additive or coating reduces the amount of loss during processing and final application and results in longer retention of the desirable properties of the additive (e.g., plasticizer effect

Table 4. Compatibility of Haloalkyl Phosphate with Resins (Stauffer Chemical Co., undated a,c; Guide to Plastics, Properties and Specification Charts, 1975)

Haloalkyl Phosphate	CEP			DCEP			[illegible]
Ratio of resin to haloalkyl phosphate	1:1	3:1	9:1	1:1	3:1	9:1	
Butadiene-acrylonitrile rubber, medium-high acrylonitrile content	C	C	C				
Butadiene-styrene	I	I	I	I	I	I	
Cellulose acetate	C	C	C	C	C	C	C
Cellulose acetate butyrate	C	C	C	C	I	C	I
Cellulose nitrate	C	C	C	C	C	C	C
Cellulose propionate	C	C	C	C	C	C	
Cellulose triacetate	I	I	C	I	I	C	
Chlorinated rubber				C	C	C	
Chlorinated wax	C	C	C	C	C	C	
Ethyl cellulose	C	C	C	C	C	C	C
Neoprene	I	I	I	I	I	C	
Nylon	I	I	I	I	I	I	
Phenolic resin	C	C	C	C	C	C	
Polyethyl acrylate	C	C	C	C	C	C	
Polymethyl methacrylate	C	C	C	C	C	C	C
Polystyrene	I	I	I	C	C	C	C
Polyvinyl acetate	C	C	C	C	C	C	C
Polyvinyl butyrate	C	C	C	C	C	C	C
Polyvinyl chloride	I	C	C	C	C	C	C
Polyvinyl chloride acetate				C	C	C	C
Shellac	I	C	C	C	C	C	C
Urea-formaldehyde	C	C	C	C	C	C	

C - Compatible

I - Incompatible

Table 5. Stability of Selected Haloalkyl Phosphates (Stauffer Chemical Co., 1972a,b, 1973a,b,c; Michigan Chemical Corp., 1974 b; Southwest Research Institute, 1964; Chevron Chemical Co., 1973)

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]	Stable	Stable	Stable	Stable	[illegible]

[illegible]

Table 6. Thermally Induced Weight Loss of Haloalkyl Phosphate Flame Retardants[a] (Great Lakes Chemical Corp., 1973a,b,c)

Percent Weight Loss	Temperature, °C		
	DBPP	CEP	DCPP
1	215	120	203
5	270	187	238
10	285	206	254
25	300	230	277
50	310	249	296
75	320	261	
95		270	

[a] Determined on Perkin-Elmer TGS-1 Thermobalance (20°C/min under nitrogen)

and flame retardancy). Table 7 compares the evaporative loss of CEP to that of three other common phosphate plasticizers.

Table 7. Comparative Volatility of Tris(2-chloroethyl) Phosphate and Other Phosphate Plasticizers at 160°F (Stauffer Chemical Co., undated a)

Plasticizer[a]	Loss of Plasticizer at 160°F, Weight Percent	
	one week	two weeks
Tricresyl phosphate	0.0	0.0
Dioctyl phosphate	0.2	0.2
Tris(2-chloroethyl) phosphate	0.7	4.65
Dibutyl phosphate	7.7	21.60

[a] 30 g plasticizer in a petri dish

3. Principal Contaminants in Commercial Materials

Table 8 summarizes information on contaminants present in commercial haloalkyl phosphates. The identity of the contaminants was often not available. Shell Chemical Co. (1973a) reports that commercial dichlorvos contains 7% of "insecticidally active, related compounds" but does not list them. This may also apply to naled, since it is the bromine addition product of dichlorvos. DBPP is available in two grades, "standard" and "purified"; after three hours at 135° C, the purified grade yields only 1.5% volatiles, while the standard grade emits 7 to 11%. Michigan Chemical Corp. (1974b) lists three volatile organic chemicals in their high purity DBPP (0.8% volatiles after 3 hours at 135°): 1,2-dibromo-3-chloropropane; 1,2,3-

Table 8. Contaminants in Commercial Haloalkyl Phosphates (Stauffer Chemical Co., undated a,b,c,d; Great Lakes Chemical Corp., 1973a,b,c,d, 1974; Michigan Chemical Corp., 1962, 1974b; Tenneco Chemicals, Inc., undated; Shell Chemical Co., 1973a)

Haloalkyl Phosphate	DBPP	CPP		[illegible]	Dichlorvos	Naled
Test						
Organic impurities weight percent, max.[a]	1,2-Dibromochloropropane, 0.05 1,2,3-Tribromopropane, 0.05 2,3-Dibromopropanol, 0.20			Tris(2,3-dichloro-n-propyl) phosphate, ca. 3%	Insecticidally active, related compounds, 3%	
Maximum water content, weight percent		0.1		0.1		
Acid number, maximum mgKOH/g	0.1	0.2	0.1	0.1		
Maximum ash, weight percent	0.6	0.5				
Volatiles, percent loss after 3 hours	1.5 (135°C) (b) 7-11 (135°C) (c)	0.5 (105°C)				
Color, maximum platinum-cobalt units APHA	25-125[b]; 100-350[c]	50	50	100		

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[a] In Michigan Chemical Corp., 1974b (Firemaster LV-T23P:0.8% volatiles at 135°C, 3 hours)

[b] Purified, Michigan Chemical Corp., 1962; Tenneco Chemicals, undated

[c] Standard, Michigan Chemical Corp., 1962; Tenneco Chemicals, undated; Stauffer Chemical Co., undated d

tribromopropane; and 2,3-dibromopropanol. The low acid numbers (mg KOH/g product required for neutralization) in the commercial products suggest that phosphoric acid and mono- and dialkyl-phosphate esters, if present, are minor impurities. Commercial DCPP (isopropyl isomer) does contain a high concentration (5%) of tris(2,3-dichloro-1-propyl) phosphate (the n-propyl isomer). If one can assume potential impurities from analogies with DBPP, then the potential impurities in CEP, CPP and DCPP include chlorinated alcohols and chlorinated hydrocarbons.

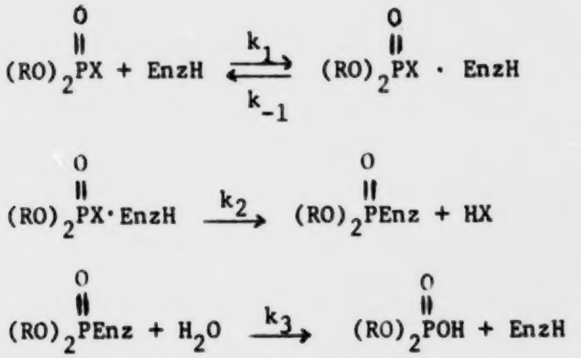
B. Chemistry

1. Chemistry Involved in Use

a. Insecticides

Dichlorvos and naled are related in biological activity. Naled, which is produced by brominating dichlorvos, reacts with natural thiols to regenerate dichlorvos. It is suspected that regenerated dichlorvos is the active agent in naled (Eto, 1974).

Organophosphate insecticidal activity results from a phosphorylation reaction with an esteratic site of the enzyme cholinesterase (ChE). Normally, ChE will remove and degrade acetylcholine (ACh) from nerve synapses. Since phosphorylated ChE is unable to catalyze ACh degradation, ACh accumulates and disrupts the normal operation of the nervous system (Metcalf, 1971). The following reaction sequence describes the enzyme phosphorylation kinetics (Metcalf, 1971).



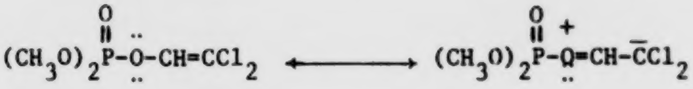
$$\mathrm{(RO)_2\overset{\overset{O}{\|}}{P}X + EnzH \underset{k_{-1}}{\overset{k_1}{\rightleftharpoons}} (RO)_2\overset{\overset{O}{\|}}{P}X \cdot EnzH} \qquad (1)$$

$$\mathrm{(RO)_2\overset{\overset{O}{\|}}{P}X{\cdot}EnzH \xrightarrow{k_2} (RO)_2\overset{\overset{O}{\|}}{P}Enz + HX} \qquad (2)$$

$$\mathrm{(RO)_2\overset{\overset{O}{\|}}{P}Enz + H_2O \xrightarrow{k_3} (RO)_2\overset{\overset{O}{\|}}{P}OH + EnzH} \qquad (3)$$

The hydrolysis of the phosphorylated ChE, Reaction 3, is so slow that it requires several days. Until it is hydrolyzed, the ChE remains inactive. There is some controversy over the site of phosphorylation on ChE. According to Bedford and Robinson (1972), phosphorylation takes place at the hydroxyl group of the serine unit, while O'Brien (1960) and Metcalf (1971) have suggested that the reaction might occur at an imidazole of a histidine unit.

Insecticidal activity of the haloalkyl phosphates is related to the P-O bond strength and the leaving group properties of the halogenated enol anion. Dichlorvos is typical of the phosphorylating agents with the structure described by the P-XYZ system, where X, Y, and Z are usually the elements H, C, N, O, S, or halogens. Eto (1974) has described the requirements of the -XYZ system of a good leaving group. The P-X bond must be weak, and Z must be strongly electron-withdrawing. In general, the phosphorus-hetero atom bonds are strong as the result of pπ-dπ bonding between available electron pairs of the hetero atom, X, and the vacant 3d orbitals of the phosphorus atom. P-X bond strength can be weakened by pπ bonding between X and Y. For dichlorvos, the following conjugation weakens the P-O bond:



$$(CH_3O)_2\overset{\overset{O}{\|}}{P}-\underset{..}{\overset{..}{O}}-CH{=}CCl_2 \longleftrightarrow (CH_3O)_2\overset{\overset{O}{\|}}{P}-\underset{..}{\overset{+}{O}}{=}CH-\bar{C}Cl_2$$

The chlorinated enol anion, which is the leaving group in the phosphorylation reaction, is similarly stabilized by resonance:

$$\bar{O}-CH{=}CCl_2 \longleftrightarrow O{=}CH-\bar{C}Cl_2$$

b. Fire Retardants

Haloalkyl phosphates impart fire retardant properties to natural and synthetic polymers. These include the natural cellulosic polymers of wood products and fabrics (e.g.,cellulose acetates) and synthetic polymers such as the polyolefins, polyurethanes, and polyesters (Napier and Wong, 1972;

Pattison and Hindersinn, 1971; Lyons, 1970; Schwarz, 1973). The chemistry of fire retardation is rather complex and only partially understood. Haloalkyl phosphates combine the individual contributions of phosphorus compounds and alkyl halides with the known phosphorus-halogen synergism (Pattison and Hindersinn, 1971).

A fire retardant can suppress combustion by interfering with any stage of the polymer combustion sequence (Pearce and Liepins, 1975; Bostic _et al._, 1973; Hilado, 1974; Pattison and Hindersinn, 1971). This sequence can be characterized as follows:

(1) Heating the polymer
(2) Polymer pyrolysis to yield monomeric organic substrates
(3) Vaporization of the pyrolysis products
(4) Ignition
(5) Combustion and propagation.

It is possible that the haloalkyl phosphates contribute to retardation at each stage.

Two mechanisms have been suggested for the haloalkyl phosphate contribution to fire retardation in the heating (first) state: (1) decomposition of alkyl halogen bonds in preference to polymer bonds and (2) the formation of a surface char which subsequently insulates the polymer from the heat source (Bostic _et al._, 1973; Pearce and Liepins, 1975). Alkyl halogen bonds break at lower temperature than the polymer bonds and, since alkyl halide bond breakage is endothermic, alkyl halide pyrolysis results in reduced energy availability for the polymer degradation. In contrast, polymer degradation is an exothermic process and would increase the energy available for further degradation.

The haloalkyl phosphates improve fire resistance in the polymer pyrolysis stage by altering the products to yield a carbonaceous char instead of monomeric, volatile residues (Pearce and Liepins, 1975; Hilado, 1974). The char-forming reactions reduce the volatile hydrocarbon available for combustion and also create a barrier between the flame and the polymer, which subsequently insulates the polymer from the external heat sources (first stage) and retards vaporization of monomeric residues (third stage).

The char results from a process called intumescence, in which surface coke is foamed by escaping gases (Pearce and Liepins, 1975). The char contains a large proportion of high molecular weight aromatic hydrocarbons and phosphate (O'Mara *et al.*, 1973; Napier and Wong, 1972). The chemical reactions which alter the course of the pyrolysis and produce the char formation are only partly understood. It appears that several reaction sequences participate simultaneously. In one sequence, pyrolysis yields phosphoric acid. This subsequently yields a polyphosphoric acid glaze over the polymer surface (Schwarz, 1973). In another sequence, the alkyl halides form olefins and hydrogen halides (Napier and Wong, 1972; Schwarz, 1973). Polyphosphoric acid and hydrogen halide then participate by a synergistic reaction sequence to alter the products of the polymer degradation. Apparently, they induce the degrading polymer to form olefins within its chain, rather than to degrade *via* chain-breaking reactions. Then the polymeric olefins crosslink to yield the surface coke. The sequence of the coking reaction has been partially characterized. In cellulose (polyol), the acidic polyphosphates and hydrogen halides yield olefins by dehydrating the polymer (Learmonth and Twaite, 1969; Schuyten *et al.*, 1954). In synthetic polymers, including polyolefins and polyesters, the hydrogen halides and polyphosphoric acids participate in olefin-forming reactions by a series of partial oxidations and subsequent dehydrations (O'Mara et al., 1973).

Hydrogen halides generated during pyrolysis interrupt the chain reactions of hydrocarbon combustion (Pattison and Hindersinn, 1971; Hilado, 1974). Figure 2 illustrates a simplified mechanism for the proposed radical reaction chain. The hydrogen halides have two possible effects on the combustion process: suffocation and flame poisoning. Suffocation is caused by large volumes of hydrogen halides in the combustion zone which reduce the oxygen concentration. Flame poisoning results from the halide atoms trapping some free-radicals, in particular the hydroxy radicals (Hilado, 1974; Pattison and Hindersinn, 1971). Schwarz (1973) and O'Mara et al. (1973) suggest that the radical inhibition mechanism is most effective in the flame's preignition zone.

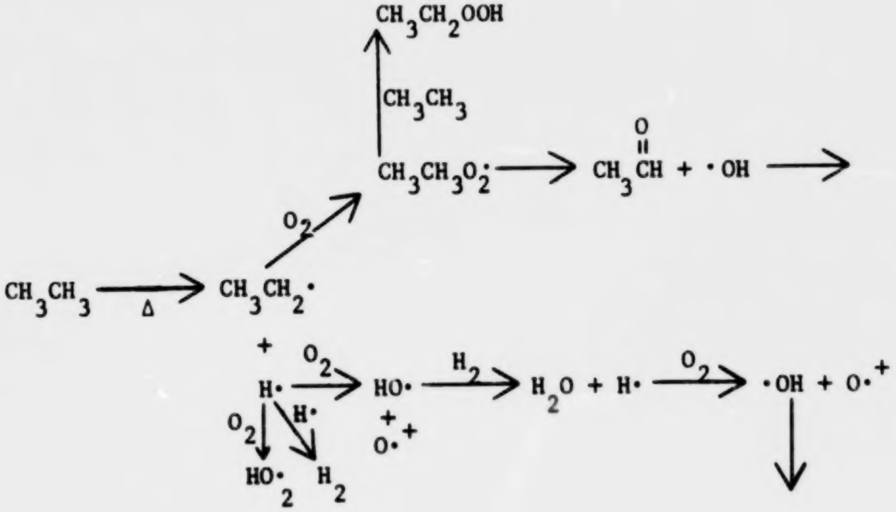


Figure 2. A Simplified Mechanism for the Combustion of Ethane (Pattison and Hindersinn, 1971)

2. Hydrolysis

a. General

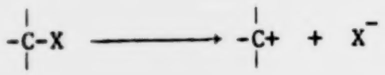
Hydrolysis and related reactions of haloalkyl phosphates can proceed by either bimolecular (4) or monomolecular (5) reaction kinetics. While the rate of the former is proportional to the concentrations of both haloalkyl phosphate and the nucleophile (e.g. hydroxide), the rate of the latter is proportional only to the concentration of the haloalkyl phosphate.

$$X: + RY \xrightarrow{k_1} RX + Y: \qquad (4)$$

$$RY \underset{k_{-1}}{\overset{k_1}{\rightleftarrows}} R^+ + Y^-$$

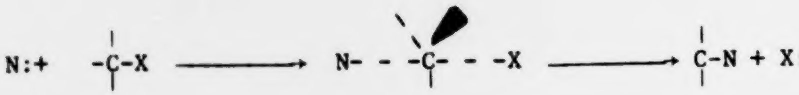
$$R^+ + X^- \xrightarrow{fast} RX \qquad (5)$$

Hydrolysis and related reactions can proceed at one of several sites in haloalkyl phosphates: (1) at the phosphorus atom, (2) at any of the three alkyl carbons of the P-O-C portion of the molecule, or (3) at the alkyl carbon atom attached to the halogen. For reactions at carbon atoms, monomolecular kinetics correspond with an S_N1 mechanism, in which a carbonium ion is formed (See reaction (6), where X is either halide (Br^- or Cl^-) or phosphate [$(RO)_2P(O)O^-$]).



$$-\overset{|}{\underset{|}{C}}-X \longrightarrow -\overset{|}{\underset{|}{C}}+ \; + \; X^- \qquad (6)$$

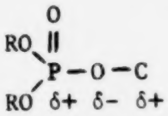
Bimolecular kinetics fit an S_N2 mechanism, in which the nucleophile attaches to the carbon as the bond to the leaving group is broken [see (7)].



$$N:+ \; -\overset{|}{\underset{|}{C}}-X \longrightarrow N- - -\overset{\diagdown \; \blacktriangle}{\underset{|}{C}}- - -X \longrightarrow \overset{|}{\underset{|}{C}}-N + X: \qquad (7)$$

Hydrolysis and related ionic reactions shift from S_N2 to S_N1 mechanism in the following order of alkyl groups: methyl, primary alkyl, secondary alkyl, and tertiary alkyl. Addition of alkyl groups to the C-X carbon atom will stabilize carbonium ions formed in the S_N1 mechanism and at the same time cause steric hindrance for the S_N2 transition state (Cram and Hammond, 1964; Bedford and Robinson, 1972). Although the phosphorus atom reacts by similar mechanisms, the chemistry of the phosphorus and carbon atoms are not identical (Hudson, 1965; Fest and Schmidt, 1973).

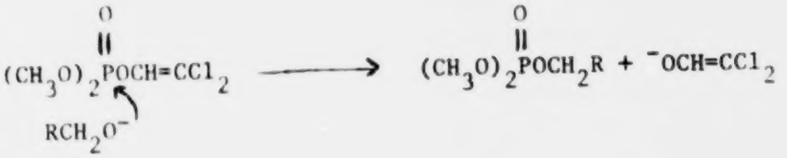
Alkyl phosphates have the polarity illustrated by (8). Hydrolysis and related ionic reactions generally proceed by nucleophilic



(8)

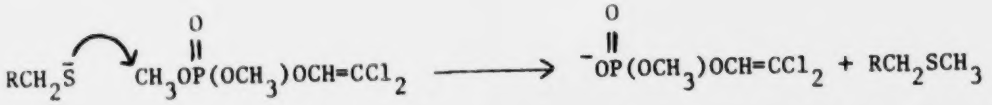
attack at the phosphorus or carbon atom. Protonation (or complex formation with Lewis acids) at an oxygen (either the carbonyl or the C-O-P) can catalyze the reaction (Eto, 1974). The preference for reaction at the phosphorus or carbon atom has been explained by application of the Pearson theory of "hard" and "soft" acids and bases (Pearson and Songstad, 1967; Bedford and Robinson, 1972; Fest and Schmidt, 1973). The ions are characterized by the size of their charge densities: highly charged, relatively compact ions are "hard" and less densely charged are "soft." Hard acids prefer reaction with hard bases, and soft acids prefer reaction with soft bases. In phosphate esters, the phosphorus atom is a hard acid site and the carbon atom is a soft acid site. While hard bases such as hydroxide, ammonia, and alkoxide ion prefer reaction at phosphorus, soft bases such as water, alkyl amines, and mercaptides

(RS^-) prefer reaction at carbon (Fest and Schmidt, 1973). The Pearson theory can aid in predicting whether a substrate will react in a biological system as a phosphorylating agent or an alkylating agent. For example, dichlorvos reacts as a phosphorylating agent (9) with enzyme serinyl groups (hard bases), while glutathione residues (soft bases) prefer alkylation (10) (Bedford and Robinson, 1972; Rowlands, 1967).



$$(CH_3O)_2\overset{\overset{O}{\|}}{P}OCH{=}CCl_2 \quad \underset{RCH_2O^-}{} \longrightarrow (CH_3O)_2\overset{\overset{O}{\|}}{P}OCH_2R + {}^-OCH{=}CCl_2$$

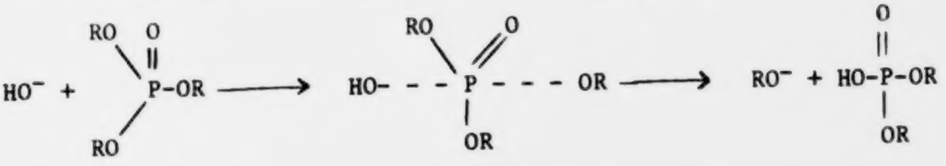
(9)



$$RCH_2\bar{S} \quad CH_3O\overset{\overset{O}{\|}}{P}(OCH_3)OCH{=}CCl_2 \longrightarrow {}^-O\overset{\overset{O}{\|}}{P}(OCH_3)OCH{=}CCl_2 + RCH_2SCH_3$$

(10)

Trialkyl phosphate hydrolysis rate and mechanism are generally pH dependent. In hydrolysis, rate minima occur at approximately pH 1 and pH 8, and a rate maximum appears between pH 4 and 5 (Kosolapoff, 1950). In alkaline conditions, hydrolysis takes place by bimolecular kinetics. Hydroxide ion (a hard base) attacks at phosphorus (a hard acid site) and forms a trigonal bipyramid intermediate (11) (Hudson, 1965; Fest and Schmidt, 1973).

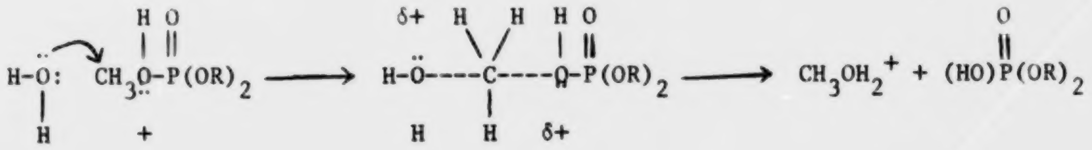


$$HO^- + (RO)_2\overset{\overset{O}{\|}}{P}{-}OR \longrightarrow HO{-}{-}{-}\underset{OR}{\overset{RO\ \ O}{P}}{-}{-}{-}OR \longrightarrow RO^- + HO{-}\underset{OR}{\overset{\overset{O}{\|}}{P}}{-}OR$$

(11)

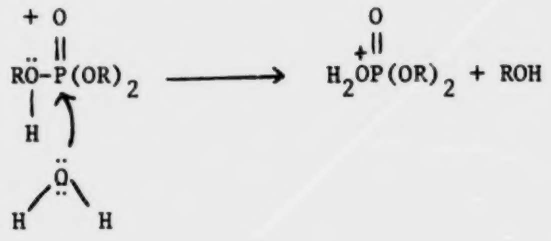
This yields a secondary phosphate ester, which under basic conditions forms the anion, $(RO)_2P(O)O^-$. The secondary phosphate ester does not hydrolyze unless it is exposed to "drastic" alkaline conditions (Kosolapoff, 1950; Cherbuliez, 1973).

When trialkyl phosphates are hydrolyzed in mildly acidic or neutral conditions, the reaction proceeds by water attacking at a carbon atom. The reaction is aided by protonation at C-O-P oxygen, according to Fest and Schmidt (1973). With methyl esters, hydrolysis and related reactions are bimolecular (S_N2), but with increasingly larger alkyl groups, the mechanism shifts toward S_N1 character (Bedford and Robinson, 1972). The reaction sequence for a methyl ester is described by (12). Secondary and



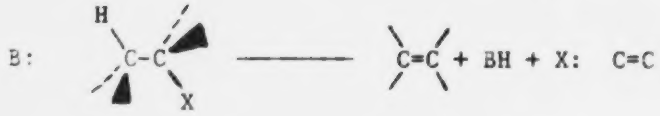
$$H\text{-}\ddot{O}(H){:} + CH_3\overset{+}{O}(H)\text{-}P(O)(OR)_2 \longrightarrow H\text{-}\overset{\delta+}{\ddot{O}}(H)\text{----}CH_3\text{----}\overset{\delta+}{O}(H)\text{-}P(O)(OR)_2 \longrightarrow CH_3OH_2^+ + (HO)P(O)(OR)_2 \qquad (12)$$

primary phosphate esters hydrolyze, although more slowly, to ultimately yield phosphoric acid. In strong aqueous acid the attack of water at phosphorus competes with reaction at carbon (Fest and Schmidt, 1973).



$$R\overset{+}{\ddot{O}}(H)\text{-}P(O)(OR)_2 + H_2\ddot{O} \longrightarrow H_2\overset{+}{O}P(O)(OR)_2 + ROH \qquad (13)$$

Alkyl halides hydrolyze slowly both by S_N1 and S_N2 mechanisms (Cram and Hammond, 1964; Bedford and Robinson, 1972). Bromine and chlorine atoms are soft bases and are better leaving groups than phosphate. In addition to substitution reactions, alkyl halides can eliminate the elements of HX in alkaline solutions to yield olefins. Elimination proceeds by bimolecular kinetics or an E-2 mechanism which is illustrated by (14).



(14)

Preference for elimination increases with increase in base strength and in the following order of alkyl halide: primary < secondary < tertiary (Cram and Hammond, 1964).

b. Fire Retardants

Tris(haloalkyl) phosphates hydrolyze at the P-O-C function rather than at the alkyl halide bond (Cherbuliez, 1973). Technical information for the commercial products describes their hydrolysis under neutral conditions as slow (Tenneco Chemicals, undated; Jones *et al.*, 1946; Michigan Chemical Corp., 1962; Stauffer Chemical Co., undated a,b,c,d).

Tables 9 and 10 record the changes in acid number (mg KOH/g of ester required to neutralize the solution) for DCPP and CEP, respectively. Hydrolysis products are not identified. The change in acid number for aqueous DBPP held at 75°C for 24 hours is also reported as insignificant (Tenneco Chemicals, undated).

Table 9. Hydrolytic Stability of Tris(1,3-dichloroisopropyl) Phosphate[a] (Stauffer Chemical Co., undated c)

		Acid Number (mg KOH/g of ester)	
Temperature, °C	Time, Days	Initial	Final
25	178	0.1	0.5
70	178	0.1	0.5
100	1	0.1	0.5

(a) 5% Aqueous Mixture of DCPP

Table 10. Hydrolytic Stability of Tris(2-chloroethyl) Phosphate in Water at Various Temperatures (Stauffer Chemical Co., undated a)

	Acid number (mg KOH/g of ester)					
Concentration of ester in water	5%			95%		
Temperature	25°C	70°C	Reflux	25°C	70°C	Reflux
Time, days						
Original	0.031	0.031	0.031	0.031	0.031	0.031
1	0.038	0.597	6.0	0.038	0.597	18.0
30	0.075	0.683	------	0.115	0.683	------
178	0.206	5.865	------	0.301	1.942	------

In acidic or basic solution, the triesters apparently hydrolyze somewhat more rapidly than under neutral conditions. Moderate hydrolysis is reported for the hydrolysis of CPP, DCPP, or DBPP in aqueous base (Stauffer Chemical Co., 1972b, 1973a,b). It is reported that DBPP dehydrohalogenates at elevated temperatures in strong aqueous alkali, but its products are not reported (Michigan Chemical Corp., 1962; Tenneco Chemicals, Inc., undated). Product literature (Stauffer Chemical Co., 1972a,b, 1973a,b) also reports that all four tris(haloalkyl) phosphates hydrolyze in aqueous acid. Their hydrolyses are described as "non-violent."

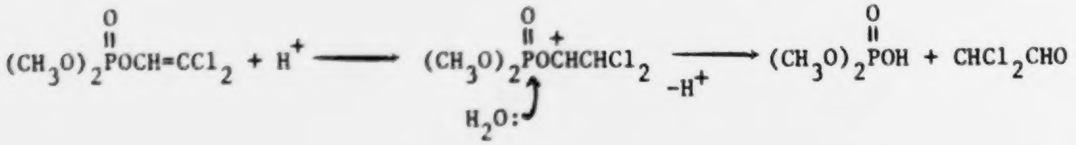
c. Insecticides

Naled and dichlorvos are both hydrolyzed rapidly under ambient environmental conditions. Studies with sterilized water, sediment, and soil indicate that biochemical hydrolysis from microbial action is much faster than that from purely chemical reactions (Getzin and Rosefield, 1968). Table 11 compares the degradation of dichlorvos in sterile soil (autoclaved) and normal soil (Getzin and Rosefield, 1968). Degradation is primarily by hydrolysis (Goring et al., 1975).

Table 11. Degradation of Dichlorvos in Chehalis Clay Loam in One Day (Getzin and Rosefield, 1968)

Soil	Percent Dichlorvos Degraded
Nonsterile	99
Autoclaved	17
Irradiated	88

Dichlorvos hydrolyzes in aqueous acid by a mechanism other than those listed for the other selected haloalkyl phosphates. The reaction proceeds according to (15); the phosphorus oxygen-bond of the vinyl group breaks after olefin protonation (Eto, 1974; Fest and Schmidt, 1973). Hydrolysis products are dichloroacetaldehyde and dimethylphosphate, which can subsequently hydrolyze (Lewis and Geldart, 1966; Shell Chemical Co., 1973a). Biochemical hydrolysis of dichlorvos yields desmethyl dichlorvos and methanol (Eto, 1974) and, therefore, since biochemical hydrolysis seems to be an important hydrolytic pathway, desmethyl dichlorvos would be an expected environmental degradation product.



$$(CH_3O)_2\overset{\overset{O}{\|}}{P}OCH{=}CCl_2 + H^+ \longrightarrow (CH_3O)_2\underset{H_2O:}{\overset{\overset{O}{\|}\,+}{P}}OCHCHCl_2 \xrightarrow[-H^+]{} (CH_3O)_2\overset{\overset{O}{\|}}{P}OH + CHCl_2CHO \qquad (15)$$

Table 12 lists hydrolysis half-lives for aqueous dichlorvos at different temperatures and pH values. The half-life decreases rapidly when the pH is changed from slightly-acid to neutral solution. While a two unit pH change from 7 to 9.1 (at 38°C) decreased the half-life by less than a factor of two, a change from 5.4 to 7 increased the half-life by a factor of ten (Attfield and Webster, 1966). The half-life is relatively constant in the range of pH 1 to 5 (Muhlmann and Schrader, 1957).

Table 12. Hydrolysis Data for Dichlorvos in Aqueous Solution

Series	Temperature °C	pH	Half-life
Variable pH (a)	38	1.1	60 hours
	38	5.4	77
	38	6	35
	38	7	7.7
	38	8	5
	38	9.1	4.5
Variable pH (b)	70	1.	2.3 hours
	70	2.	3.4
	70	3.	3.4
	70	4.	3.0
	70	5.	2.8
	70	6.	1.4
	70	7.	0.45
	70	8.	--
Variable Temperature (b)	0	1-5	1030 days
	10	1-5	240
	20	1-5	61.5
	30	1-5	17.3
	40	1-5	5.8
	50	1-5	1.66
	60	1-5	0.88
	70	1-5	0.164

(a) Attfield and Webster, 1966
(b) Muhlmann and Schrader, 1957

Naled appears to hydrolyze more slowly than dichlorvos. Eto (1974) reports that it hydrolyzes completely within two days (at room temperature) to yield bromodichloroacetaldehyde, dimethyl phosphate, and hydrogen bromide. Information on commercial naled (Chevron Chemical Co., 1970) states that naled hydrolyzes at 10% per day under neutral or slightly acidic conditions.

3. Oxidation

The literature contains no specific information on the oxidation of tris(haloalkyl) phosphates. According to the manufacturers' literature (Stauffer Chemical Co., 1972a,b, 1973a,b; Tenneco Chemicals, undated), they are stable under usual environmental conditions.

Dichlorvos can be oxidized at its double bond. The addition of bromine to dichlorvos to yield naled is an oxidation reaction (Eto, 1974). Other chemical reactants are expected to oxidize the dichlorvos double bond in typical reactions (Cram and Hammond, 1964). However, dichlorvos is more rapidly degraded in soil by hydrolysis than by oxidation (Goring et al., 1975).

4. Photochemistry

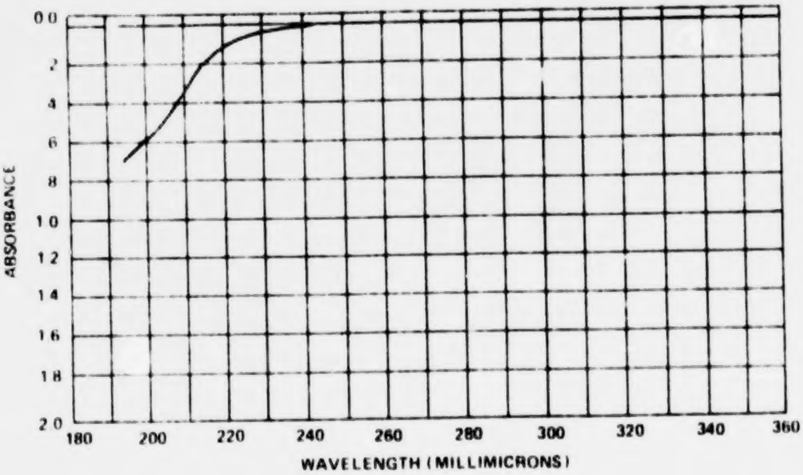
There is no specific information on the photochemistry of the haloalkyl phosphates. Available information does suggest that some photochemical degradation occurs. Eto (1974) notes that, in the presence of moisture, ultraviolet irradiation will cause hydrolysis of phosphate esters. Manufacturers' data (Chevron Chemical Co., 1970) states that naled is degraded by sunlight and should be stored either in brown glass or in lightproof packing. However, it is not clear from the available information whether the degradation is caused by photolysis of the naled or by reactions involving impurities in the commercial product. Mitchell (1961) investigated the possibility that irradiation at 253.7 nm degrades dichlorvos, but the results were inconclusive.

Technical bulletins (Stauffer Chemical Co., undated a,b, c,d) report that the commercial tris(haloalkyl) phosphates are stable to sunlight but might exhibit some instability in some resins, i.e., polyesters, acrylics, and urethane. Table 13 records changes in acid number for commercial DCPP exposed to sunlight.

Table 13. Effect of Exposure of Tris(1,3-dichloroisopropyl) Phosphate to the Light of a Weather-O-Meter at 179°F (Stauffer Chemical Co., undated c)

	Initial	After 1100 Hours Exposure
Color, Gardner-Holdt	1	6½
Acid Number, Mg KOH/g	0.1	25

Figures 3 and 4 record the ultraviolet spectra of dichlorvos and alkyl halides, respectively. Dichlorvos does not absorb light wavelengths above 260 nm. Maxima for the alkyl halides appear at approximately 173 nm for chlorides and 203 nm for bromides; extinction coefficients increase with increasing halogen content (Calvert and Pitts, 1966). No ultraviolet spectra were found for simple trialkyl phosphates or the remaining haloalkyl phosphates. Since sunlight cuts off below 290 nm, the available data suggest that direct excitation of the haloalkyl phosphates is quite unlikely.



Concentration	0.1 µl/ml
Solvent	methanol
Cell Path	1 mm
Manufacturer	Shell Chemical Co
Quality	99%

Figure 3. Ultraviolet Spectrum of Dichlorvos (Gore et al., 1971)

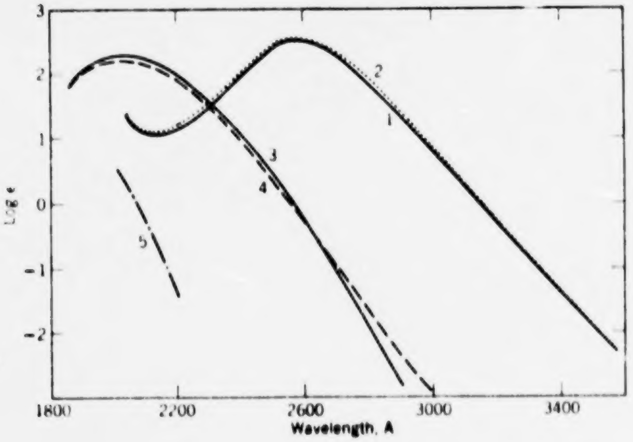


Figure 4. Absorption Spectra of: (1) Methyl Iodide [$CH_3I(g)$]; (2) Ethyl Iodide [$C_2H_5I(g)$]; (3) Methyl Bromide [$CH_3Br(g)$]; (4) Ethyl Bromide [$C_2H_5Br(g)$]; (5) Ethyl Chloride [C_2H_5Cl] in Alcohol Solution (Calvert and Pitts, 1966)

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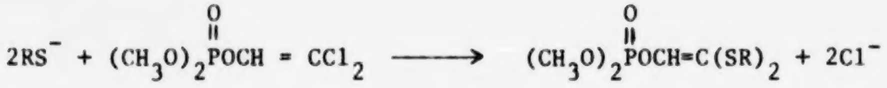
5. Other Reactions

Other reactions of haloalkyl phosphates are expected to resemble those of alkyl halides and alkyl phosphates. Their general reactions are summarized in Table 14. The ionic reactions will proceed by the mechanisms described in the "Hydrolysis" discussion (Section I-B-2, p. 18). Haloalkyl phosphate reactions with amines are important to commercial fire retardant use in that they are not compatible with amine curing agents (Great Lakes Chemical Corp., 1973a,b,c).

Eto (1974) reports that mercaptides will react with the vinylidene chlorines of dichlorvos to yield the dimercapto compound (16).



$$2RS^- + (CH_3O)_2\overset{O}{\overset{\|}{P}}OCH = CCl_2 \longrightarrow (CH_3O)_2\overset{O}{\overset{\|}{P}}OCH{=}C(SR)_2 + 2Cl^- \qquad (16)$$

Both naled and dichlorvos will react with iron but not with stainless steel (Chevron Chemical Co., 1970; Shell Chemical Co., 1973a).

Table 14. General Reactions of Alkyl Phosphates and Alkyl Halides (Cram and Hammond, 1964; Fest and Schmidt, 1973; Bebikh et al., 1974; Eto, 1974; Kosolapoff, 1950; Bedford and Robinson, 1972)

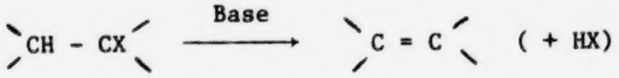
A. Alkyl Halides (X = Cl or Br)

1. Substitution

$$RX + Y: \longrightarrow RY + X^{\ominus}$$

Y = water; alcohols; thiols; amines; iodide; hydride (e.g. $LiALH_4$); nitrile; organometallics; other nucleophiles

2. Elimination (with strong bases)

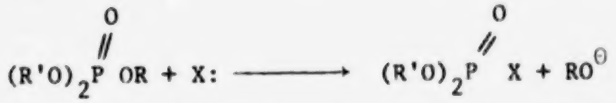


$$\rangle CH - CX \langle \xrightarrow{\text{Base}} \rangle C = C \langle \quad (+ HX)$$

B. Alkyl Phosphates

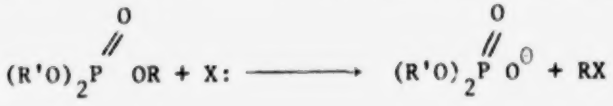
1. Substitution

a. At phosphorus - "hard" bases: X = alkoxide; ammonia



$$(R'O)_2\overset{O}{\overset{/\!/}{P}}OR + X: \longrightarrow (R'O)_2\overset{O}{\overset{/\!/}{P}}X + RO^{\ominus}$$

b. At carbon - "soft" bases: X - alcohol; secondary amines



$$(R'O)_2\overset{O}{\overset{/\!/}{P}}OR + X: \longrightarrow (R'O)_2\overset{O}{\overset{/\!/}{P}}O^{\ominus} + RX$$

2. Reaction with phosphorus oxychloride

$$(RO)_3PO + POCl_3 \longrightarrow (RO)_2P(O)Cl + (RO)P(O)Cl_2$$

II. Environmental Exposure Factors

A. Production/Consumption

1. Volume Produced

Table 15 summarizes production data for selected haloalkyl phosphates. Information on non-halogenated organophosphates has been included for comparison.

The available data for the haloalkyl phosphates used as fire retardants refer mainly to the four selected: DBPP, DCPP, CEP, and CPP. Some of the reported quantities might include other haloalkyl phosphates and the related haloalkyl phosphonates.

Table 16 reports the approximate market shares of the individual esters. Calculations are based on industry estimates (Stauffer Chemical Co., 1975; Tenneco Chemicals, Inc., 1975; Great Lakes Chemical Corp., 1975; Michigan Chemical Corp., 1975). The 30 million pounds include approximately three million pounds of haloalkyl phosphonates. Industrial sources contacted in this study generally rated DBPP as the highest-volume ester of the four haloalkyl phosphates. Its estimated annual production ranged from eight million pounds (Stauffer Chemical Co., 1975) to eleven million pounds (Tenneco Chemicals, Inc., 1975). While this study has ranked the three chlorinated esters in the relative order DCPP>CEP>CPP, the industrial sources have suggested that production patterns fluctuate and that the order might vary in other years.

Both naled and dichlorvos are produced in approximately equivalent volumes. Production of each is estimated at three million pounds.

Table 15. **Estimated Annual Production of Haloalkyl Phosphates and Related Chemicals**

	Production in Thousands of Pounds		
	Fire Retardants	Insecticides	
	Haloalkyl Phosphates	Dichlorvos	Naled
1964		260(f)	
1965			
1966		912(g)	
1967			
1968			
1969	9,500(a)		
1970			
1971		<1,000(h) 2,430(i)	2,000(i)
1972	15,000(a)		
1973	24,000(a)		
1974	24,600(b)	1,000-4,000(i)	1,000-4,000(i)
1975	24,000-30,200(c,d,e)	3,000(j)	3,000(k)

(a) Nobles, 1974
(b) Schongar and Zengierski, 1975
(c) Tenneco Chemicals, Inc., 1975
(d) Great Lakes Chemical Co., 1975
(e) Stauffer Chemical Co., 1975
(f) Eichers *et al.*, 1968
(g) Andrilenas, 1974; value is for farm use - mainly cattle
(h) Lawless *et al.*, 1972
(i) von Rumker *et al.*, 1974
(j) Shell Chemical Co., 1975
(k) Chevron Chemical Co., 1975

Table 16. Estimated Market Share of Haloalkyl Phosphate Fire Retardants

Fire Retardant	Percent of Market(a)	Annual Production, In Thousands of Pounds(b)
Tris (2,3-dibromopropyl) phosphate	30-40	9,000-12,000
Tris (1,3-dichloropropyl) phosphate	20-33.3	6,000-10,000
Tris (2-chloroethyl) phosphate	10-33.3	3,000-10,000
Tris (2-chloropropyl) phosphate	10	3,000
Halogenated Phosphonates	10	3,000
Total		24,000-38,000

(a) From personal contact with producers.

(b) $\text{Annual Production} = \frac{30{,}000 \times \text{Percent of Market}}{100}$

2. Producers, Major Distributors, Importers, Sources of Imports, and Production Sites

Table 17 lists current producers of the selected haloalkyl phosphates; production sites are mapped in Figure 5. Table 18 summarizes current historical information on producers which was gathered from the Directory of Chemical Producers (SRI, 1974, 1975), U.S. International Trade Commission (USITC, 1959-1974) reports, and personal contact with the manufacturers. Some differences were noticed in information gathered from each source. The final list of current producers (Table 17) was based upon personal contact with producers. A few apparent errors in the Directory of Chemical Producers (SRI, 1974, 1975) are worthy of note. While SRI reports that Chevron Chemical Co. is the sole producer of naled, sources contacted at both Chevron Chemical Co. (1975) and Shell Chemical Co. (1975) have stated that Shell Chemical Co. is the sole manufacturer and Chevron Chemical Co.

Table 17. Current Producers of Haloalkyl Phosphates[a]

Company	Production Site	Haloalkyl Phosphates Produced
Shell Chemical Co. Agricultural Div.	Denver, Col. Mobile, Ala.	naled dichlorvos
Stauffer Chemical Co. Specialty Chemical Div.	Gallipolis Ferry, W.Va.	DCPP CPP CEP
Dow Chemical Co.	Midland, Mich.	DBPP
Great Lakes Chem. Corp.	El Dorado, Ark.	DBPP
Nease Chemical Co., Inc.	State College, Pa.	DBPP
Northwest Indust., Inc. Michigan Chem. Corp., Subsidiary	St. Louis, Mich.	DBPP
Tenneco Chemicals, Inc.	Fords, N.J.	DBPP
White Chemical Corp.	Bayonne, N.J.	DBPP

(a) From SRI (1974, 1975), USITC (1974) and personal communication with producers.

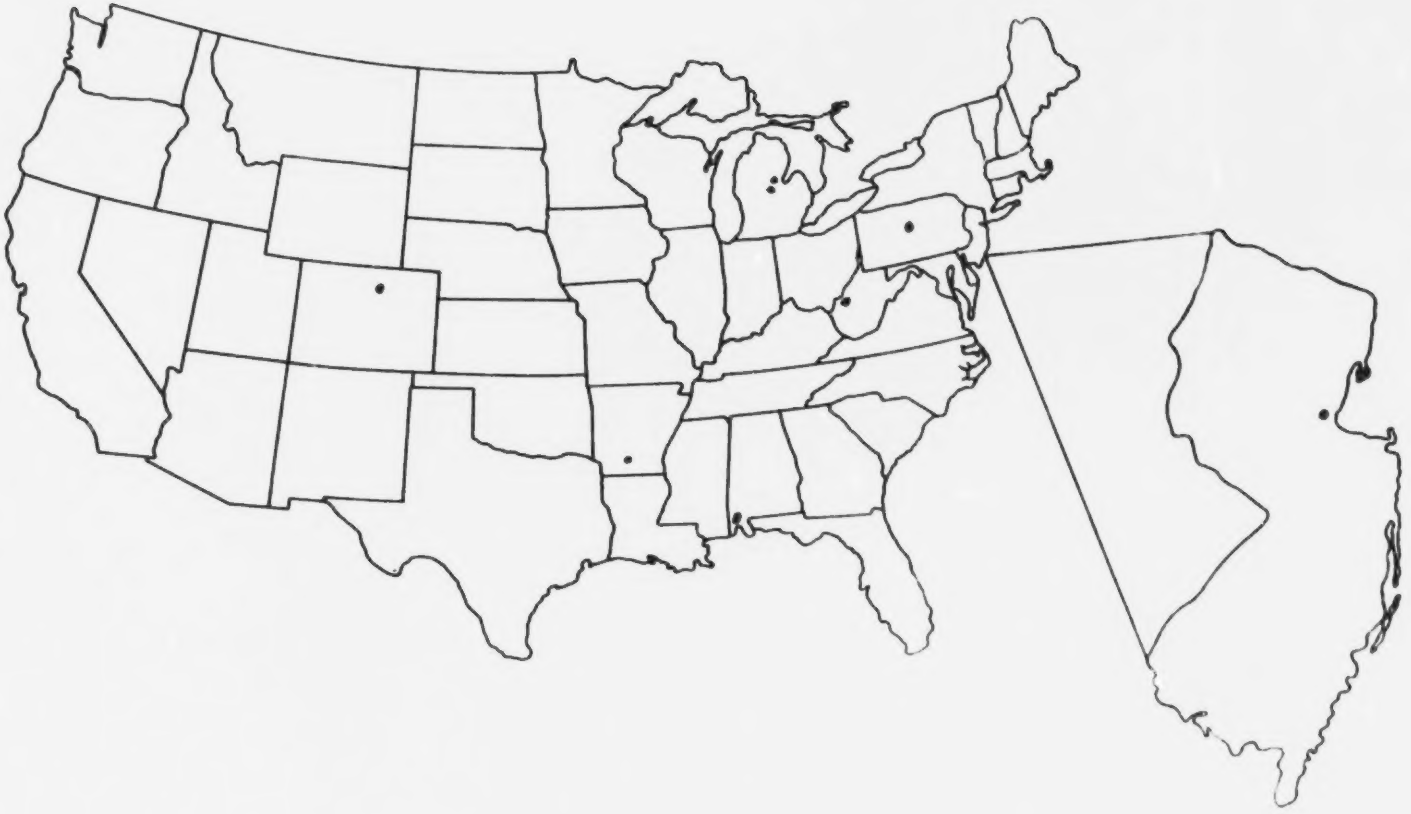


Figure 5. Production Sites of Haloalkyl Phosphates

Table 18. Past and Present Producers of Haloalkyl Phosphates, 1959-1975

	Dichlorvos		Naled	DBPP							CEP				CPP		DCPP	
	Shell Chemical Co. Mobile, Ala. Denver, Col	Montrose Chemical Co. Newark, N.J.	Shell Chemical Co. Mobile, Ala. Denver, Col.	Michigan Chemical Corp. St. Louis, Mich.	Great Lakes Chem. Corp. El Dorado, Ark.	White Chemical Corp. Bayonne, N.J.	Dupont & Co. Deepwater, N.J.	Dow Chemical Co. Midland, Mich.	Nease Chemical Co. State College, Pa.	Tenneco Chemicals, Inc. Fords, N.J.	Stauffer Chemical Co. Gallipolis Ferry, W.Va.	Union Carbide Corp.	Celanese Chemical Corp.	Humble Chemical Co.	Stauffer Chemical Co. Gallipolis Ferry, W.Va.	Celanese Chemical Corp.	Stauffer Chemical Co. Gallipolis Ferry, W.Va.	Michigan Chemical Corp. St. Louis, Mich.
Personal Contact (1975)	X	/	X	X	X	W	/	W	W	X	X	/	-	-	X	-	X	/
SRI, 1975	X	/	/	X	X	X	/	/	/	/	X	/	/	/	/	/	X[a]	/
1974	X	/	/	X	X	X	/	/	/	/	X	/	/	/	/	/	X[a]	/
USITC 1974	X	/	X	na	na	na	na	na	na	na	X	/	/	/	X	/	na	na
1973	X	/	X	X	/	/	/	X	X	/	X	X	/	/	X	/	/	/
1972	X	/	X	X	/	/	/	/	/	X	X	X	/	/	X	/	/	/
1971	X	/	X	X	/	/	/	/	/	/	X	X	/	/	X	/	/	/
1970	X	/	X	X	/	/	/	/	/	/	X	X	/	/	/	/	/	/
1969	X	/	X	X	/	/	/	/	/	/	X	X	/	/	/	/	/	/
1968	X	/	X	X	/	/	/	/	/	/	X	X	/	/	/	/	/	X
1967	X	/	X	X	/	/	/	/	/	/	/	X	/	/	/	/	/	/
1966	X	/	X	X	/	/	/	/	/	/	/	X	/	/	/	/	/	/
1965	X	/	X	X	/	/	/	/	/	/	/	X	/	/	/	/	/	/
1964	X	/	X	X	/	/	X	/	/	/	/	/	X	X	/	/	/	/
1963	X	X	X	X	/	/	X	/	/	/	/	/	X	X	/	/	/	/
1962	X	X	X	X	/	/	X	/	/	/	/	/	X	X	/	/	/	/
1961	X	X	/	X	/	/	X	/	/	/	/	X	X	X	/	X	/	/
1960	X	X	/	X	/	/	X	/	/	/	/	/	X	X	/	/	/	/
1959	X	X	/	X	/	/	X	/	/	/	/	/	X	/	/	/	/	/

- Not contacted

X Manufacturer

/ Not a manufacturer

W Withdrawing from manufacture in 1975

[a] Listed as tris(2,3-dichloropropyl) phosphate

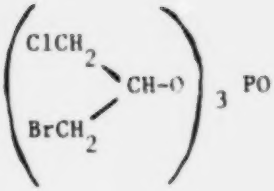
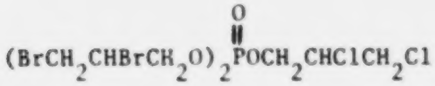
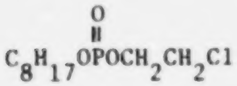
na Information not available

(Ortho Division) is its major formulator and distributor. SRI (1974, 1975) lists Stauffer Chemical Co. as a manufacturer of tris(2,3-dichloro-n-propyl) phosphate; Stauffer Chemical Co. (1975), however, reports that its product consists of 95% tris(1,3-dichloroisopropyl) phosphate and a small quantity of the isomeric tris(2,3-dichloro-n-propyl) phosphate. Although SRI (1974, 1975) lists Michigan Chemical Corp. as a manufacturer of tris(1-bromo-3-chloroisopropyl) phosphate, Michigan Chemical Corp. (1975) states that it does not manufacture the ester.

Relatively few companies now manufacture haloalkyl phosphates. Shell Chemical Co. is the sole producer of both dichlorvos and naled. Until Montrose Chemical Co. lost a patent dispute with Shell Chemical Co. in 1963, they were also a producer (Montrose Chemical Co., 1975). Stauffer Chemical Co. is the only current producer of tris(chloroalkyl) phosphates. Three current producers of DBPP reported that they either have withdrawn or will withdraw from the market by the end of 1975: White Chemical Corp., Dow Chemical Co., and Nease Chemical Co. Three producers of DBPP remain: Michigan Chemical Corp., Great Lakes Chemical Corp., and Tenneco Chemicals, Inc.

Table 19 lists foreign producers of haloalkyl phosphates. Several esters other than the four haloalkyl phosphates selected for this study are available from foreign producers (Kuryla, 1973). No information is available on amounts imported into the U.S. (TSUS, 1969, 1971). Some CPP may have been formerly imported from ICI (U.K.)(Stauffer Chemical Co., 1975).

Table 19. Foreign Producers of Haloalkyl Phosphate Flame Retardants (Kuryla, 1973)

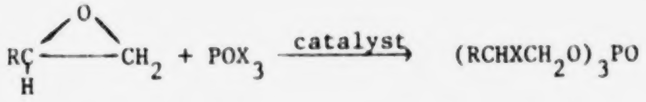
Haloalkyl Phosphate	Producer
Tris(2,3-dibromopropyl) phosphate	Nippon Oils (Japan) Kalk (W. Germany) Bromine Compounds (Israel) Berk (U.K.) Billant (France)
Tris(2-chloropropyl) phosphate	Daihachi (Japan) British Celanese (U.K.) Bayer (W. Germany) SUC Ugine Kuhlman (France)
	Teijin Chemical (Japan)
 $(BrCH_2CHBrCH_2O)_2\overset{O}{\overset{\parallel}{P}}OCH_2CHClCH_2Cl$	Daihachi (Japan)
Tris(2,3-dichloro-n-propyl) phosphate	Daihachi (Japan) Nippon Oils (Japan) SUC Ugine Kuhlman (France)
Tri(3-chloro-n-propyl) phosphate	Nippon Oils (Japan)
Tris(1-chloroisopropyl) phosphate	British Celanese (U.K.)
 $C_8H_{17}O\overset{O}{\overset{\parallel}{P}}OCH_2CH_2Cl$	Daihachi (Japan)

3. Production Methods and Processes

a. Fire Retardants

The tris(haloalkyl) phosphate fire retardants are prepared by reaction of the appropriate alcohol and phosphorus oxychloride in the presence of a tertiary amine base, such as pyridine (Reaction 1) or by reaction of the appropriate epoxide and phosphorus oxyhalide in the presence of an acid catalyst such as phosphorus trichloride, aluminum trichloride, zirconium chloride, or titanium chloride (Reaction 2) (Kosolapoff, 1950; Cherbuliez, 1973; van Wazer, 1961). When alcohols react with phosphorus oxychloride, alkyl chloride formation competes with ester production. Formation of

$$RCH_2OH + POCl_3 + B: \xrightarrow[\text{solvent}]{} (RCH_2O)_3PO + 3BH^+Cl^- \qquad (1)$$



$$RCH(O)CH_2 + POX_3 \xrightarrow{\text{catalyst}} (RCHXCH_2O)_3PO \qquad (2)$$

alkyl chlorides can be held to relatively small amounts in reactions using primary alcohols, but their production from reactions using secondary alcohols cannot be held to low levels (van Wazer, 1961). For economic reasons, reactions between epoxides and phosphorus oxychloride (Reaction 2) are preferred for preparing tris(chloroalkyl) phosphates. CEP, CPP, and DCPP are prepared commercially by reaction of ethylene oxide, propylene oxide, and epichlorohydrin, respectively, with phosphorus oxychloride. Since epibromohydrin and phosphorus oxybromide are relatively expensive, DBPP is seldom prepared from these starting materials (Samuel *et al.*, 1958; Great Lakes Chemical Corp., 1975), but is produced commercially from 2,3-dibromopropanol and phosphorus oxychloride, Reaction 1 (Tenneco Chemicals, Inc., 1975). Van

Wazer (1961, 1968) has described some of the pertinent commercial aspects of processes based on Reactions 1 and 2.

In production processes based upon Reaction 1, phosphorus oxychloride is added to primary alcohol at temperatures from 0° to 20°C. Van wazer (1961) reports that a 24-hour digestion is required in the absence of a catalyst or some method for removing liberated hydrogen chloride. Techniques for removing hydrogen chloride include addition of bases, such as tertiary amines, or stripping by means of inert gas or reduced pressure. Phosphorus trichloride is an effective catalyst. In the product purification step, the reaction mixture is neutralized, washed, and stripped of excess alcohol by distillation. The ester is distilled in vacuo. Reported yields range from 85 to 95%.

Van Wazer (1961) describes the production of CEP from ethylene oxide and phosphorus oxychloride as a very exothermic process. The process is carried out in a closed reactor. Liquid ethylene oxide is fed into phosphorus oxychloride under a slight positive pressure of an inert gas; this reduces the hazard of explosive decomposition of ethylene oxide. The rate of epoxide addition is described as sufficient to allow the reactor cooling system to dissipate the high heat generated by the reaction. The ethylene oxide is reportedly added in slight excess. After excess epoxide is removed by evacuation of the reactor, the haloalkyl phosphate is purified by washing. Van Wazer (1961) reports that the commercial product is usually not distilled.

b. Insecticides

Dichlorvos is produced commercially from chloral and trimethyl phosphate, Reaction 3 (Sittig, 1967; Tedder et al., 1975; Shell Chemical Co., 1975). According to Sittig (1967) the two starting materials

$$(CH_3O)_3P + Cl_3CHO \longrightarrow (CH_3O)_2P(O)(OCH{=}CCl_2) + CH_3Cl \qquad (3)$$

are reacted in a stirred, jacketed kettle of conventional design maintained at temperatures of 10° to 150°C. The preferred molar ratio for chloral and trimethyl phosphate reportedly is between 1:2 and 2:1. Sittig (1967) reports that the reaction does not require catalysts. Product recovery steps include dilution with water, washing with benzene, and extraction into chloroform. The chloroform is then stripped *in vacuo*.

Naled is prepared commercially by brominating dichlorvos in the presence of ultraviolet irradiation (Casida *et al*., 1962; Sittig, 1967; Eto, 1974). Sittig (1967) describes the reactor as a Pfaudler glass-lined kettle with baffles. It is jacketed for heating and cooling and contains a water-cooled, quartz mercury vapor light source, which is installed within an immersion well. The best yields are achieved by brominating in the temperature range of 0° to 30°C and by adding the bromine slowly (10 to 11 hours) to a solution of dichlorvos. While carbon tetrachloride is the preferred solvent, other inert polar organic solvents could be used. Sittig (1967) reports that product work-up consists of stripping solvent and excess bromine *in vacuo* (50 mm Hg) at a maximum temperature of 80°C. The recovered product is 90 to 93% naled. It represents essentially a quantitative yield based on dichlorvos.

4. Market Prices

Table 20 lists market prices of haloalkyl phosphates. The prices of the fire retardants have been increasing over the past three to four years. Shell Chemical Co. (1975) stated that the price drop for dichlorvos results from the upcoming expiration of its patent, which will increase market competition.

Table 20. Market Prices of Selected Haloalkyl Phosphates

	Price in dollars per pound[a]			
	1973	1974	1975	1976
Dichlorvos		4.25	4.50	3.30
Naled		1.90 to 1.95	2.75	2.30
Tris(2,3-dibromopropyl) phosphate		0.75	0.86	0.94 to 0.98[b]
Tris(2-chloroethyl) phosphate	0.49	0.49	0.55	0.67
Tris(2-chloropropyl) phosphate		0.54 to 0.67	0.67	0.67
Tris(1,3-dichloroisopropyl) phosphate	0.65	0.70		0.74

[a] Prices quoted by the producers

[b] $0.94 by tanker; $0.96 for truckload; $0.98 for less than truckload

5. Market Trends

a. Fire Retardants

The growth rate for halogenated phosphate fire retardants is projected to exceed 20% annually into the 1980's (Nobles, 1974; Schongar and Zengierki, 1975). Major influences which will expand the market are the general growth of plastics and synthetic fibers and an increase in the number of products covered by Federal flammability standards. Total fire retardant growth is expected to increase most dramatically in home furnishings and transportation.

Haloalkyl phosphate fire retardants are consumed primarily in polyurethane foams and in cellulosic acetate and polyester fabrics. While

DBPP is principally used in fabrics, its use in polyurethane foam appears to be small but still significant. The chloroalkyl phosphates are predominantly used in polyurethane foams (See "Major Uses," p. 46). New markets could result from haloalkyl phosphate promotion as additives for other resins (See "Projected Uses," p. 37). Raw material shortages could reduce haloalkyl phosphate growth rate.

DBPP consumption will probably grow most rapidly in polyester fabrics. Annual growth of cellulosic acetate fibers is forecast at 1.8%, compared to 8.8% for polyester in wearing apparel and 6.7% in home furnishings (Wallace, 1971, 1974). Polyester single-knit fabrics, which include that used in children's sleepwear, are forecasted to increase at 12% annually, reaching 437 million pounds in 1979 from 221 million pounds in 1973 (Wallace, 1974). No alternative additive has been suggested as a viable economic competitor to DBPP in the polyester market. In polyurethane foams, DBPP has lost some ground to competitors such as bromopropanol (Monsanto, 1975; Stauffer Chemical Co., 1975). The newly-marketed chloroalkyl phosphate--tetrakis(2-chloroethyl)ethylene diphosphate--could put additional pressure on DBPP's market in polyurethane foams (Olin, 1976).

Growth of chloroalkyl phosphates will probably be greatest in polyurethane foams used in furniture, transportation, and household goods (See "Major Uses," p. 46). Tables 21 and 22 summarize projected growth for all plastics and for polyurethane foams, respectively. Haloalkyl phosphates are not used as fire retardants for construction materials. No alternatives to chloroalkyl phosphates in urethane foams were suggested as economic competitors in the near future.

Table 21. Major Markets for Plastics (Schongar and Zengierski, 1975)

	Market Size (1973) in Millions of Pounds	Percent Fire-Retarded (1973)	Projected Growth of Fire-Retarded Plastics, Percent Annually
Building & Construction	5,154	10	13-15
Electrical/Electronic	1,638	22.5	10-12
Transportation	1,551	20	17
Furnishings	1,095	15	17-20
Packaging	5,830	1	
Housewares	1,363	1-2	10
Appliances	938		
Other	6,831	1	
	24,400	6.2	

Table 22. Growth Projected for Polyurethane Foams (Frey, 1974b)

	Rigid Foam		Flexible Foam	
	Projected Market (1978) in Millions of Pounds	Percent Annual Growth	Projected Market (1978) in Millions of Pounds	Percent Annual Growth
Transportation	74-81	8-10	515-616	8-12
Furniture	79-103	12-18	561-616	7-9
Construction	320-378	18-22		
Refrigerators and Freezers	121-132	10-12		
Industrial Insulation	35-42	12-16		
Bedding			154-169	7-9
Carpet Underlay			123	8-10
Textile Laminate			25	0
Miscellaneous	38-44	7-10	119	7

B. Uses

1. Major Uses, Quantities, and Sites of Use

a. Fire Retardants

The only important uses of DBPP, CEP, CPP, and DCPP are as fire retardant additives to plastics and synthetic textiles. The compounds are only used in plastics and textiles which must pass flammability standards. Many alternative fire retardant additives and techniques compete with these chemicals (See "Alternatives to Use," p. 58). An additive is selected to fit many criteria, including cost, effectiveness in fire retardation, stability to withstand the conditions of processing and use, and effects on performance and esthetics of the material (Drake, 1966).

Table 23 summarizes information on the consumption of DBPP, CEP, CPP, and DCPP. The information was gathered from available literature sources and from contacts with industry. Although available information discusses general properties and uses of haloalkyl phosphate fire retardants, no literature or industry source describes, either qualitatively or quantitatively, the overall consumption of haloalkyl phosphates. However, more information is expected soon, since the National Fire Retardant Chemical Association (1975) is now assembling marketing data and expects to have information available sometime after July, 1976.

Literature and industrial sources concur on the major markets for the selected haloalkyl phosphates, but some disagreement exists on minor market segments. The dominant markets for haloalkyl phosphates are polyester and cellulosic acetate (This term is used for cellulose acetate and cellulose triacetate) fabrics and polyurethane foam. The markets for individual

Table 23. Consumption of Haloalkyl Phosphate Fire Retardants (Stauffer Chemical Co., 1975, 1976; Tenneco Chemicals Inc., 1975; Dupont, 1975; Michigan Chemical Corp., 1975; Great Lakes Chemical Corp., 1975; Hooker Chemicals and Plastics Corp., 1975; Frey, 1974b)

Chemical	Estimated Consumption for 1975, in Thousands of Pounds (a)	Major Uses	Minor Uses
Tris(2,3-dibromopropyl) phosphate	9,000-12,000	Textiles -Polyesters -Cellulosics Plastics -Flexible polyurethane foams	Plastics -Some use in polystyrene foams, in polyester, in acrylic and in other resins -Some use in acetate adhesives
Tris(2-chloroethyl) phosphate	3,000-10,000	Plastics -Flexible and rigid polyurethane foams	Plastics -Polyesters -Acetate adhesives -Other resins Textiles
Tris(2-chloropropyl) phosphate	3,000	Plastics -Flexible polyurethane foams	Plastics -Other resins Textiles
Tris(1,3-dichloro-2-propyl) phosphate	6,000-10,000	Plastics -Rigid polyurethane foams	Plastics -Other resins Textiles

(a) From Table 16.

chloroalkyl phosphates are similar to each other but substantially different from the DBPP market. Polyurethane foam (rigid and flexible) dominates consumption of chloroalkyl phosphates, while their consumption in the textiles industry is minor. Although the consensus of industry is that consumption in textiles is small, there exists some disagreement over whether or not chloroalkyl phosphate use is, in fact, insignificant (Stauffer Chemical Co., 1975; Hooker Chemicals and Plastics Corp., 1975; Frey, 1974a). In contrast, DBPP consumption in cellulosic acetate and polyester fabrics is larger than its consumption in plastics (Tenneco Chemicals Inc., 1975; Stauffer Chemical Co., 1975). Polyurethane foam is the predominant consumer of DBPP, among its plastic applications. One industry source (Great Lakes Chemical Corp., 1975) has estimated that about two-thirds of the DBPP is consumed by the textiles.

i. In Textiles

As noted earlier, DBPP is primarily used for polyester and cellulosic acetate fabrics. It was suggested that the ratio of its consumption in polyester to cellulosic acetate is about 2:1 (Great Lakes Chemical Corp., 1975). Some use of DBPP and the chloroalkyl phosphates in acrylic fabrics has also been mentioned (Hooker Chemicals and Plastics Corp., 1975; Frey, 1974a).

DBPP or chloroalkyl phosphate fire retardants can be added to textiles by the producer or the dyer and finisher. Addition by dyers and finishers appears to be more common. Cellulosic acetate can be treated during fiber spinning (Drake, 1971; Stauffer Chemical Co., 1975; FMC Corp., 1975). DBPP is usually added at 6 to 10% to the spinning dope and diffused through the fiber by the heat and pressure of the spinning (McGeehan and Maddock, 1975; Williams, 1974). Polyester fibers cannot be fire retarded by this technique, since their spinning temperatures exceed those at which DBPP is stable. Either the producer or the textile finisher can fire retard polyester and cellulosic acetate fabrics with a topical application of DBPP. Pad-dry techniques seem to be the most common method. DBPP is padded onto the fabric from organic solvents or aqueous emulsions (3 to 10% DBPP), squeezed through padded rollers to remove excess solvent, and then dried quickly. Residues are removed by scouring (Williams, 1974; McGeehan and Maddock, 1975; Drake, 1971). DBPP can also be applied during batch dying by vapor emulsion (Williams, 1974; McGeehan and Maddock, 1975).

Consumption data on polyester and cellulosic acetate fibers in fabric production are summarized in Table 24. Fiber producers and their production sites and capacities are listed in Table 25. Non-textile uses of the fibers do not consume haloalkyl phosphates (e.g., polyester cord for tires and cellulose acetate for cigarette filters). Fabric dyers and finishers are summarized in Table 26.

Children's sleepwear (sizes 0 to 6X) is perhaps the largest market for fabrics fire retarded with DBPP (McGeehan and Maddock, 1975; Great Lakes Chemical Corp., 1975; Stauffer Chemical Co., 1975). Fabrics for children's sleepwear are predominantly single knits. Wallace (1971, 1974) has estimated single knit fabric consumption at 155.3 million pounds of cellulosic acetates (1970) and 221.0 million pounds of polyester (1973). There is no information on the quantities of haloalkyl phosphates consumed in children's sleepwear. Smaller amounts of the haloalkyl phosphates are consumed in draperies and upholstery fabrics (Michigan Chemical Corp., 1975).

Table 24. Annual Production of Polyester and Cellulosic Acetate Fibers (In Millions of Pounds) (Wallace, 1971, 1974)

	Polyester Fibers (1973)	Acetate (Textile) Fibers (1970)
Production	3,016.1	498.9
Domestic shipments	2,978.0	479.1
Imports	135.2	3.2
Domestic Consumption	3,113.2	482.3
Apparel	1,977.6	
Knit fabrics	1,164.4	253.8
Woven fabrics	813.2	218.6 (a)
Home Furnishings	516.3	
Carpets and rugs	194.8	
Bedsheets and cases	190.1	
Draperies and curtains	60.1	
Blankets	49.9	
Upholstery	7.9	
Other	13.5	
Industrial and other areas	619.3	9.9

(a) Includes 2.1 million pounds in blankets

Table 25. Polyester and Cellulosic Acetate Textile Producers and Sites of Production (Wallace, 1971, 1974; SRI, 1975)

Producer and Site	Annual Capacity (1974) In Millions of Pounds	
	Polyester	Cellulose Acetate and Triacetate
Akzona Inc.	125	
American Enka, Div.		
Central, S.C.	x	
Lowland, Tenn.	x	
Allied Chemical Corp.		
Fibers Div.	6 (a)	
Columbia, S.C.	x	
Beaunit Corp.	15	
Fibers Div.		
Elizabethtown, Tenn.	x	
Dow Badische Co.	5	
Anderson, S.C.	x	
Celanese Corp.		
Celanese Fibers Co.		[illegible]
Cumberland, Md.		x
Narrows, Va.		x
Rock Hill, S.C.		x
Rome, Ga.		x
E.I. duPont deNemours & Co.		
Textile Fibers Dept.	1040	[illegible]
Camden, S.C.	x	
Chattanooga, Tenn.	x	
Kinston, N.C.	x	
Old Hickory, Tenn.	x	
Waynesboro, Va.		x
Wilmington, N.C.	x	
Eastman Kodak Co.	310	90
Carolina Eastman Co. Div.		
Columbia, S.C.	x	
Tennessee Eastman Co., Div.		
Kingsport, Tenn.	x	x
Fiber Industries Inc.	595	
Salisbury, N.C.	x	
Shelby, N.C.	x	
Greenville, S.C.	x	
Palmetto, S.C.	x	
FMC Corp.	95	45
American Viscose Div.		
Meadville, Pa.		x
Fiber Div.		
Lewiston, Pa.	x	
Front Royal, Va.	x	
Hoechst Fibers Inc.	225	
Spartanburg, S.C.	x	
Monsanto Co.	155	
Monsanto Textile Co.		
Decatur, Ala.	x	
Guntersville, Ala.	x	
Phillips Petroleum Co.	70	
Phillips Fibers Corp.		
Rocky Mount, N.C.	x	
Fibers International Corp.		
Guayama, P.R.	x	
Rohm and Haas Co.	63	
Fibers Div.		
Fayetteville, N.C.	x	
Texfi Industries, Inc.	30	
Fibers Div.		
Asheboro, N.C.	x	
New Bern, N.C.	x	
Total	2788	[illegible]

(a) Experimental plant

Table 26. Textile Dyers and Finishers (McGeehan and Maddock, 1975)

MANUFACTURER	SITE
1. Burlington Mills	Greensboro, North Carolina
2. Collins and Aikman	New York, New York
3. Cone Mills	Greensboro, North Carolina
4. Dan River	Danville, Virginia
5. Deering Milliken Corporation	Spartanburg, South Carolina
6. Fieldcrest	Eden, North Carolina
7. Graniteville Company	Graniteville, South Carolina
8. Guilford Mills	Greensboro, North Carolina
9. M. Lowenstein and Sons	New York, New York
10. Reeves Brothers	New York, New York
11. Riegel Textile Corporation	New York, New York
12. Russell Corporation	Alexander City, Alabama
13. Springs Mills	Fort Mill, South Carolina
14. J. P. Stevens and Company	Garfield, New Jersey
15. United Merchants and Manufacturers	New York, New York
16. United Piece Dye Works	Hightstown, New Jersey
17. West Point Pepperell	West Point, Georgia

Durability of the DBPP treated fabrics is one of the most important factors in its selection as an additive for polyester and cellulosic acetate fabrics. Children's sleepwear is required to meet flammability standards after 50 machine washes with subsequent 30 minute drying (McGeehan and Maddock, 1975). This washing and drying is considered to be representative of the treatment encountered during the lifetime of the product. A fire-retarded textile's ability to pass flammability standards throughout the lifetime of laundering and use (e.g., contact with urine, sweat, and water) is defined as its durability (Drake, 1966). Fabrics treated with additives such as alumina and borate salts are non-durable and may not be used in sleepwear. These inorganic fire retardants are acceptable in rugs and carpets from which they will not normally leach.

Other important factors in the choice of DBPP as a fire retardant for polyester and cellulosic fabrics include its favorable effects on the fiber properties and esthetic qualities of the woven fabrics. The risk of unfavorable health effects to humans, such as contact dermatitis, was reported to be comparatively low based upon tests on treated fabrics (McGeehan and Maddock, 1975; Morrow _et al_., 1975).

ii. Plastics

Polyurethane foams are the dominant plastic to which haloalkyl phosphate fire retardants are added (Frey, 1974a; Stauffer Chemical Co., 1975). Addition to polyurethane foams is considered to dominate the consumption of DCPP, CPP and CEP and is also the major use of DBPP among plastics (Tenneco Chemicals, Inc., 1975; Stauffer Chemical Co., 1975; Great Lakes Chemical Corp., 1975). The haloalkyl phosphates are added to both rigid and flexible foams. Consumption in flexible foams appears to be greater than in rigid foams (Howarth, et al., 1973; Hooker Chemicals and Plastics Corp., 1975; Levek and Williams, 1975-76). Small amounts of DBPP are reported as an additive for polystyrene foam (Levek and Williams, 1975-76; Great Lakes Chemical Corp., 1975). Information on haloalkyl phosphate use in other plastics is inconclusive.

Howarth and coworkers (1973) estimate that fire retarded polyurethane requires the following approximate combinations (by weight) of phosphorus and halogen: 0.5% phosphorus and 4-7% bromine or 1% phosphorus and 10-15% chlorine. This corresponds to about 10% DBPP (Tenneco Chemicals Inc., 1975) or 15% of a chloroalkyl phosphate in the product. While it is reported that fire retardants can be added to the finished foam, haloalkyl phosphates are almost always added before the foam is blown (Skochdopole, 1966; Hooker Chemicals and Plastics Corp., 1975; Olin Corp., 1976). Following the addition of the haloalkyl phosphates, the polyurethane is blown and cured at approximately 200 to 300°F (100°-150°C) (Frey, 1974b; Olin, 1976; Bayha and Loh, 1975).

Table 27 describes the polyurethane foam market. No quantitative information is available on distribution of foams treated with haloalkyl phosphates. Flexible foams are principally used for cushioning. Uses of cushioning treated with haloalkyl phosphates include automotive and aircraft interiors, institutional bedding, cushions, and upholstered furniture (Frey, 1974b; Schongar and Zengierski, 1975; Michigan Chemical Corp., 1975; Howarth et al., 1973). Rigid foams have a considerable number of applications, including insulation, furniture, automobile interior parts, and water flotation devices. Haloalkyl phosphates are not added to rigid foams used for building insulation; these foams use less expensive fire retardants (Great Lakes Chemical Corp., 1975; Stauffer Chemical Co., 1975).

Table 27. Consumption of Polyurethane Foams in 1973 (In Millions of Pounds) (Wallace, 1974)

	Flexible	Rigid
Furniture	400	55
Transportation	350	50
Bedding	110	
Carpet Underlay	80[a]	
Textile Laminates	25	
Packaging	20	
Refrigerators and Freezers		75
Construction		140
Flotation		10
Miscellaneous	65	17
Total	1050	367

[a] An additional 100 million pounds of "bonded" polyurethane foam carpet underlays are estimated to have been produced from scrap foam.

b. Insecticides

Naled and dichlorvos are consumed only as pesticides. While they are primarily insecticides, they are also used as miticides and anthelmintics. Table 28 lists their most important uses. They are used where low toxicity and short residual times are desired.

Most dichlorvos is formulated into resin strips (popularly known under its Shell Chemical Co. trademark, "No-Pest Strip"). Shell Chemical Co. (1975) estimated that about 80% of dichlorvos goes into the resin strips. They are primarily consumed as household items. Dichlorvos is also formulated into aerosol sprays for use in households and by pest control operators (exterminators). Von Rumker *et al*. (1974) ranked dichlorvos as one of three active ingredients most frequently used by pest control operators. Aerosol formulations of dichlorvos are the most popular among pest control operators. The largest consumption of naled appears to be by public health programs; it is primarily used for mosquito and fly control. Von Rumker *et al*. (1974) reported naled consumption of 412,000 pounds (active ingredients) in a survey they conducted among state (35 responding) and municipal (22 responding) agencies. Public health programs in the southern United States are estimated to be the heaviest users (Chevron Chemical Co., 1975). Other relatively important uses for naled are crop and ornamental plant spraying. Naled is particularly important as a preharvest spray for vegetables (Berg, 1976; Chevron Chemical Co., 1975).

Table 28. Major Uses of Dichlorvos and Naled (Berg, 1976; Shell Chemical Co., 1975; Chevron Chemical Co., 1975)

- DICHLORVOS
  - PVC Resin Strips ("No-Pest Strip")
    - Households
    - Pest Control Operators (exterminators)
    - Animal Barns
    - Other Uses
  - Aerosol Sprays
    - Households
    - Pest Control Operators (exterminators)
  - Anthelmitics for Swine, Horses, and Dogs
  - Flea Collars
- NALED
  - Public Health Spray Programs (fly and mosquito control)
  - Preharvest Crop Spray (usually vegetables)
  - Plant Sprays
  - Animal Barns
  - Flea Collars

2. Minor Uses

Dichlorvos and naled are used only as pesticides (Shell Chemical Co., 1975; Chevron Chemical Co., 1975).

Little, if any, of the DBPP, CEP, CPP, and DCPP is consumed other than as additives for imparting fire retardancy to plastics and textiles. Possible minor uses have been mentioned, but they were not confirmed as current uses. These include use as automobile fuel and oil additives and flotation agents in uranium ore refining (Kolka, 1958; van Wazer, 1968).

3. Discontinued Uses

Reports of production and use of tris(bromochloroisopropyl) phosphate have been noted in available literature (Levek and Williams, 1975-76; SRI, 1974, 1975). However, industry sources (Stauffer Chemical Co., 1975; Michigan Chemical Corp., 1975) stated that its manufacture and use has been discontinued since it is not economically competitive with other fire retardants.

DBPP was formerly used as a fire retardant additive for viscous rayon fiber (Drake, 1971). Since DBPP treated rayon was not durable in laundering (about five launderings removed the fire retardancy), its use has ceased (FMC, 1976).

4. Projected Uses

Projected uses of DBPP, CEP, CPP, and DCPP include new applications as fire retardant additives in plastics and synthetic fibers. The new uses are of two types: new products of fibers and plastics which are now treated with the haloalkyl phosphates and new markets for haloalkyl phosphates among resins which do not currently use them as fire retardants. As the flammability regulations and standards are expanded, new products will be treated with fire retardants to meet requirements. These products include children's sleepwear (sized 7 to 14), blankets, furniture, and automotive interiors (Howarth et al., 1973; McGeehan and Maddock, 1975; Modern Plastics, 1973). An important market for fire-retarded plastic materials will be created by substitution of plastics for metal parts in automobiles (Modern Plastics, 1973; Frey, 1974b).

Haloalkyl phosphate producers are promoting their use in resins in which they are not now being consumed in significant quantities. The fire retardant formulators suggest that the haloalkyl phosphates could be effective with the resins and other materials listed in Table 29. From personal contact with producers, it appears that they are promoting new formulations of the chloroalkyl phosphates, but they are reluctant to discuss these potential markets or their proprietary formulations because of competition within the fire retardant industry.

Olin Corp. (1976) began marketing of tetrakis(2-chloroethyl) ethylene diphosphate (CEEP) in 1975. It is being promoted primarily as an additive for flexible polyurethane foams. No information was available on last year's sales or projected growth. The product is currently manufactured at pilot plant scale by another company for Olin exclusively. Olin Corp., which hold patents on CEEP, does plan to start its own production but has not specified when.

5. Alternatives to Use

a. Fire Retardants

Current regulatory actions in certain applications seem committed to textiles and plastic products which are not fire hazards. It

Table 29. Manufacturers' Suggestions of Resins and Other Materials for Which Haloalkyl Phosphates Would be Useful Fire Retardants (Modern Plastics Enclyclopedia, 1975)

Fire Retardant	Tris(2,3-dibromopropyl) phosphate	Tris(2-chloroethyl) phosphate	Tris(2-chloropropyl) phosphate	Tris(1,3-dichloroisopropyl) phosphate
ABS				
Acrylics	X	X	X	
Cellulose acetate	X	X	X	
Cellulose acetate butyrate		X	X	X
Cellulose nitrate	X	X	X	
Epoxies		X	X	X
Ethyl cellulose		X	X	X
Phenolics	X	X	X	X
Polycarbonates		X	X	
Polyesters	X	X	X	X
Polyolefins		X	X	X
Polystyrene	X	X	X	X
Polyvinyl acetate	X	X	X	
Polyvinyl chloride	X	X	X	X
Urethane foam, flexible	X	X	X	X
Urethane foam, rigid		X	X	X
Intumescent paints	X	X	X	X
Non-intumescent paints	X	X	X	X
Latex film				
Latex foam				
Neoprene				
Nitriles				X
Paper coatings	X	X		X
Potting compounds				
Rubber	X			
Shellac				X
Textile coatings	X			X
Waxes				X

appears unlikely that flammability standards will be relaxed. Thus, if a fire retardant haloalkyl phosphate has an adverse health or environmental effect, the products to which it is added will require an alternative fire retardation method or may be removed from the market. Substitute products could be produced that do not need fire retardant additives. These could be constructed of less flammable fibers or plastics, or better flammability characteristics could be designed into the product. The new products should be as similar as possible to the original in performance, esthetic characteristics, and cost.

i. Textiles

A fabric's texture and weave influence its flammability. Tightly woven, smooth-surfaced fabrics manufactured from heavy fibers are less flammable than loosely woven, napped surfaces, and sheer or fluffy piled textiles (USCPSC, 1975). Although the manufacture of the less-flammable fabrics could reduce the amount of fire retardant required, consumer demands for the more flammable textiles make it unlikely that any significant reduction of DBPP could be achieved.

Few additives are effective fire retardants for polyester or cellulosic acetate fibers (Drake, 1971). DBPP has been the additive of choice, since it is relatively inexpensive, is effective as a fire retardant, and has excellent performance. Some success has been reported for fire-retarding polyester fibers with 2,5-dibromoterephthalic acid and tetrabromobisphenol (McGeehan and Maddock, 1975). These additives are spun into the fiber. Other potential replacements might be found among combinations of phosphorus and halides such as halogenated phosphines, phosphites, or phosphonates (Howarth et al., 1973).

Cellulosic acetate and polyester can be replaced by less flammable, although more expensive, fibers. Children's sleepwear which meets flammability standards has been produced from modacrylic fibers. Modacrylics contain 35 to 85% acetonitrile copolymerized with vinyl chloride, vinylidene chloride, or vinyl bromide (McGeehan and Maddock, 1975; Wallace, 1974). Fire-retarded polyester fibers can be produced from copolymers (Wallace, 1974). Fire-retarded copolymers are formed by blending polyethylene terephthalate with a non-combustible polymer. Less flammable polyesters are produced by copolymerization with modified diols or substituted terephthalic acid.

McGeehan and Maddock (1975) have suggested that research conducted by the chemical industry is more concerned with developing fire retardants which can be topically applied by textile dyer-finishers. The greater commitment to research on new additives apparently results, in part, from demands for non-additive fire retarded copolymer fibers beyond their available production capability.

ii. Plastics

Several alternatives to the use of haloalkyl phosphates as fire retardants for polyurethane foams have been suggested. These suggestions include improved design, substitute additives, or inherently less flammable polyurethanes. McGeehan and Maddock (1975) suggest that matresses and automobile upholstery can be designed to meet existing flammability standards without any need for fire retardant chemicals, but no details are given.

For flexible and rigid polyurethane foams, haloalkyl phosphates can be replaced by other phosphorus- and halogen-containing additives. Industry sources (Monsanto, 1975; Stauffer Chemical Co., 1975) state that bromopropanol can successfully replace DBPP for some uses and is cheaper. Where more durability is required, an alternative phosphorus compound might be used. Howarth and coworkers (1973) suggest phosphites, phosphonates, and amino phosphates as possible additives for polyurethanes.

Fire-retarding monomers can be built into polyurethane foam. Brominated isocyanates or halogenated prepolymers/polyols, which can be polymerized into the polymer backbone, will yield foams surpassing flammability requirements (Howarth et al., 1973). While the required polyols are available to produce fire retarded foams, they apparently are not widely used (Frey, 1974b).

b. Insecticides

Alternatives to naled and dichlorvos include substitute insecticides or physical control methods. The old methods of household insect control, such as screening and fly-swatting, reduce insects to acceptable levels. In commercial establishments, physical methods, such as air doors, light traps, and electric grids are excellent controls and could replace dichlorvos strips for flying insects. Naled use for community mosquito spray programs can be reduced by better drainage and general maintenance of breeding areas.

Alternative insecticides, such as pyrethroids and other organophosphates such as malathion, also have low toxicity and short life times. Pyrethrum vapor dispensing devices, such as "Time Mist," can usually replace dichlorvos where a continual low level insecticide atmosphere is wanted.

C. Environmental Contamination Potential

1. General

a. Fire Retardants

Little information on haloalkyl phosphates is available from which an accurate assessment of environmental contamination potential can be made. No significant monitoring data is available on their presence in industrial waste streams, in municipal sewage, or at solid waste disposal sites. This is further complicated by the ambiguous information on biodegradation or chemical degradation in the environment (See p. 89).

The following evaluation of environmental contamination potential is quite speculative. Transport and storage are probably insignificant sources. Contamination from industrial waste streams, use (including laundering of textiles containing the compounds), and disposal is uncertain. With the possible exception of CEP, there are no apparent inadvertent sources of haloalkyl phosphates.

b. Insecticides

Naled and dichlorvos are not long-term environmental contaminants. They are relatively quickly degraded by hydrolysis. Their use as pesticides is almost their exclusive source of release to the environment.

2. From Production

No specific monitoring data or other information is available on losses of haloalkyl phosphates from production. However, relatively low losses are expected. All the esters are produced in batch reaction kettles. Since their vapor pressures are low, atmospheric emissions are expected to be insignificant. Chances of atmospheric emission are probably highest for processes which use solvent and subsequently recover the solvent by vacuum or inert gas streams. Industrial sources suggest that no solid or liquid organic wastes are produced (See "Disposal Methods," p. 73). Aqueous wastes could be produced from washing reaction kettles or equipment or from work-up. While the haloalkyl phosphate insecticides are easily degraded by chemical or biological treatment of water, it is not clear how effective these treatments are with the fire retardants.

3. From Transport and Storage

Transport and storage losses are probably negligible. Fire retardants are transported in bulk carriers or sealed metal containers. Insecticides are transported in sealed metal drums. All the haloalkyl phosphates are usually stored in sealed containers. Since their vapor pressures are quite low, venting losses should be virtually non-existent.

Accidental spills and mishandling may result in some losses. While no specific information is available on such losses, they probably are not significant.

4. From Use

a. Fire Retardants

The haloalkyl phosphate fire retardants could potentially reach the environment from waste streams generated in plants where they are added to fabrics and plastics or from the final product during its use, disposal, or recycling. Their transport to the environment could occur by atmospheric emissions, by leaching, or with the movement of small pieces of treated fabrics or plastic products. This last potential source is discussed in "Disposal Methods" (See p. 73).

Experimental laundering of treated fabric demonstrated that DBPP can be leached into wash and rinse waters. Morrow and coworkers (1975) measured DBPP surface concentrations on dacron polyester and cellulose acetate during the course of fifty launderings; their observations are summarized in Table 30. DBPP was spun into the cellulose acetate and topically applied to the polyester by the pad-dry method (See "Major Uses," p. 46). The authors observed that approximately 12% of the DBPP is lost from the polyester and that most of this loss apparently happens in the first three washings. They also concluded that negligible DBPP was lost from the cellulose acetate. Gutenmann and Lisk (1975) estimated DBPP loss during simulated laundering of a treated polyester fabric. No information is given on the initial fabric treatment. In the simulated laundering, the fabric was heated in distilled water at 140°F for 20 minutes. The authors reported that up to 10 μg DBPP per square inch of fabric are dissolved. They estimated that in a typical home laundering of six sheets (dimensions 72" x 81") in 30 gallons of water, a concentration of 6 ppm of DBPP would be released in the combined wash and rinse. No information is available on losses during laundering of polyurethane foam products, such as pillows, which would contain chloroalkyl phosphates.

Table 30. Effect of Scouring on Surface Tris(2,3-dibromopropyl) Phosphate (Morrow *et al.*, 1975)

	Dacron® Polyester*	Experimental Acetate**
DBPP Concentration		
Total - Initial, %	5.8	8.9
Surface, Initial, ppm	4300	600
Surface, 1 Wash, ppm	780	90
Surface, 3 Washes, ppm	65	90
Total - Final (After 50 Washes)	5.1	***

* Commercial fabric - Dacron® Type 54 - Thermosol® treated
** Yarn with spun-in DBPP
*** Not tested - similar tests showed essentially complete retention of DBPP

Some evidence suggests that DBPP is biodegraded by sewage microorganisms (See Section III-A, p. 87). Thus, if laundry wastes are discharged with sewage (sewer systems, septic tanks, etc.), DBPP (and possibly chloroalkyl phosphates) might degrade before release to the environment.

Haloalkyl phosphates could be lost to the environment if a treated product is inadvertently dry cleaned with a chlorinated solvent. Since this is not typical of the recommended care of the product, it is probably not a significant contamination source.

There is no information available on atmospheric emissions of haloalkyl phosphate fire retardants. Atmospheric emissions during their addition to fabrics and plastics are considered insignificant (Stauffer Chemical Co., 1975). In the lifetime of the treated material, it is possible that some haloalkyl phosphates might be exuded (Darby and Sears, 1968). Their low vapor pressures and studies on their compatibility with the resins in which they are used suggest that such release should be slow. However, there is no confirmatory experimental evidence.

b. Pesticides

The major environmental contamination source of naled and dichlorvos is quite obviously their use as pesticides. Most of the dichlorvos is apparently applied indoors and might be degraded before reaching the outdoors. Some naled is also used indoors.

5. From Disposal

a. Fire Retardants

Industrial wastes seem a minor potential source of environmental contamination. Waste streams from production are generated mostly by equipment and product washing. Blowing and molding of polyurethane foams and spinning of cellulose acetate create no-waste streams (Burr, 1971; Stauffer Chemical Co., 1975). The only major addition process of haloalkyl phosphates which might create a waste stream is the topical addition of DBPP to fabrics. This will include aqueous wastes and small quantities of organic solvent wastes. There is no information on absolute or relative quantities of these wastes. Aqueous wastes generated by textile plants will probably be treated with active sludge (Burr, 1971; Schlesinger et al., 1976). Organic wastes are probably not released directly into the environment but are probably disposed of in chemical disposal plants or incinerators (Spencer, 1976). Overall, industrial wastes may not be an important contamination source, but monitoring data is needed to confirm this suggestion.

Potential environmental contamination from disposal of treated products is inconclusive. Some of these products are recycled, but the amount is uncertain. Some of the material is apparently reused after only physical treatment, e.g., the reuse of flexible polyurethane foams for stuffing pillows and flexible and rigid polyurethane foams for carpet backing (Stauffer Chemical Co., 1975). It is also reported that some polyurethane foams are hydrolyzed for recovery of polyols (Campbell and Meluch, 1976). However, the fate of any haloalkyl phosphate additives under these conditions is unknown. One industrial source (Stauffer Chemical Co., 1975) has suggested that the majority of polyurethane foams used in automobile interiors are recycled material.

There is no information available on recycling of polyester or cellulosic fabrics. Discarded household articles probably go into municipal landfills. There is no information on how much might be incinerated, illegally dumped, or disposed of by other methods. McGeehan and Maddock (1975) have suggested that DBPP will accumulate in trash dumps and other disposal sites. However, they cite no documenting evidence.

There is no pertinent information on the potential degradation, loss, or accumulation of haloalkyl phosphates at disposal sites. They could possibly biodegrade, but this has not been tested under field conditions (Ham, 1975; Fungaroli, 1971; Kerst, 1974).

It is possible that some environmental contamination might result from transport of particulate matter containing haloalkyl phosphates. Colton and coworkers (1974) examined the possible origin of plastic materials found in the Atlantic Ocean. While the plastic particles gathered in the Atlantic are not of the type expected to be treated with haloalkyl phosphates, it is quite possible that some treated plastics could enter surface waters by a similar pathway. Colton et al. (1974) suggest that plastics found in the ocean could have resulted from municipal solid waste disposal at sea, coastal landfill operations, or ocean disposal of wastes from vessels.

b. Pesticides

It is expected that dichlorvos and naled may be released to the environment with spent dichlorvos strips and empty pesticide containers. Some unwanted or contaminated pesticide will probably be discarded also. Because of their rapid hydrolysis, dichlorvos and naled are not expected to become a contaminant.

6. Potential Inadvertent Production in Other Industrial Processes

CEP might be formed during the production of tris(2-chloroethyl) phosphite, which is commercially prepared from phosphorus trichloride and ethylene oxide (Kosolapoff, 1950; Mobil Chemical Co., 1976). Its major producer (Mobil Chemical Co., 1976) states that, under the reaction conditions used, ethylene oxide would not form CEP with any phosphorus oxychloride present as an impurity in the phosphorus trichloride. The production of CEP as a by-product is concluded to be minor (less than 0.1%).

7. Potential Inadvertent Production in the Environment

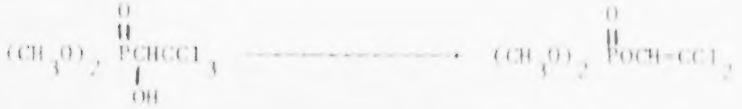
Tris(2-chloroethyl) phosphite might also be a potential precursor for inadvertent environmental production of CEP(1):

$$(ClCH_2CH_2O)_3P \xrightarrow{[O]} (ClCH_2CH_2O)_3PO \qquad (1)$$

Although most phosphites are readily oxidized to phosphates (Kosolapoff, 1950; [illegible], 1972), tris(2-chloroethyl) phosphite is reportedly stable to air oxidation (Mobil Chemical Co., 1976). However, since there is no confirming evidence to support the claim, some CEP may be formed from this source. Tris(2-chloroethyl) phosphite is produced on a commercial scale by Mobil Chemical Co. (Richmond, Va.) and Telron Chemicals (Chicago, Ill.).

Phosphite analogs of CPP, DCPP, or DBPP are not produced on a commercial scale. If one can safely judge from phosphorus chemistry, none of the commercially produced alkyl phosphates, phosphonates, phosphines, or other phosphorus compounds should yield any of the selected fire retardants in the environment.

The insecticide trichlorfon is a precursor of dichlorvos. In weakly alkaline media it hydrolyzes, as illustrated in (2). Its insecticidal activity parallels that of naled (Fest and Schmidt, 1973; Eto, 1974).



$$(CH_3O)_2\overset{O}{\overset{\|}{P}}\underset{OH}{\underset{|}{C}}HCCl_3 \longrightarrow (CH_3O)_2\overset{O}{\overset{\|}{P}}OCH{=}CCl_2 \qquad (2)$$

While trichlorfon is less toxic than dichlorvos, its insecticidal activity is considered to rely upon its conversion to dichlorvos. Its annual production is estimated at less than three million pounds (Sittig, 1971).

D. Current Handling Practices and Control Technology

1. Special Handling in Use

a. Fire Retardants

Product bulletins for fire retardant haloalkyl phosphates (Stauffer Chemical Co., 1972 a, b, 1973 a, b; Great Lakes Chemical Corp., 1973 a, b, c; Tenneco Chemicals, Inc., undated) claim that they have low hazard by ingestion, inhalation, or skin absorption. The bulletins suggest that good industrial hygiene practices, such as avoidance of prolonged skin contact, are sufficient precautions. In case of contact, soiled clothes should be removed and affected areas washed.

Since haloalkyl phosphates are excellent plasticizers, storage or transport with certain plastic equipment, in particular vinyl-based resins, should be avoided (Stauffer Chemical Co., 1972 a, b, 1973 a, b).

b. Insecticides

The insecticides dichlorvos and naled require somewhat more care in handling than the fire retardants. They are moderately toxic and can corrode metal equipment. Special instructions for handling specific insecticide formulations are specified on the product label (Chevron Chemical Co., undated a, b; Shell Chemical Co., 1973a).

The concentrated insecticides can cause eye or skin damage and can be absorbed through the skin. It is recommended that the concentrates be handled with waterproof gloves and face shield or goggles. In spraying operations, protection against inhalation and skin or eye contact should also be taken.

In application, care should be taken to avoid contamination of feed, foodstuffs, and drinking water. Dichlorvos strips should not be used in rooms where people remain immobilized (e.g., with infirmed people or infants).

The concentrated insecticides can corrode metal spraying or mixing equipment. All equipment should be thoroughly flushed with aromatic solvents after use.

3. Methods for Transport and Storage

a. Fire Retardants

Tris(haloalkyl) phosphates are stable to normal conditions of transport and storage. Storage in carbon steel, glass, or glass-lined steel containers is recommended (Stauffer Chemical Co., 1972a, b, 1973 a, b; Michigan Chemical Corp., 1974 a,b). Heating to approximately 120°F may be necessary to facilitate pumping and handling of DBPP. Heating at this temperature should be limited to three days (Michigan Chemical Corp., 1974 a, b; Stauffer Chemical Co., 1972 b). Prolonged heating can cause some evaporation loss, increase in acid number, and/or discoloration.

Tris(haloalkyl) phosphates can be shipped in quantities up to tank or railroad car lots. Manufacturers will sell quantities as small as one pound (Stauffer Chemical Co., 1972 a, b, 1973 a, b; Michigan Chemical Corp., 1974 a, b).

b. Insecticides

In storage of dichlorvos and naled one must consider health and safety factors as well as stability of the chemicals.

To prevent degradation of the insecticide, the chemicals should be kept free of water and away from light. Light protection can be achieved by using brown glass bottles or other light-proof packaging, or by storage in light-free areas. Since the chemicals are corrosive to iron and other metals, they are generally stored in glass or polyethylene liners (Shell Chemical Co., 1973 a, 1975; Chevron Chemical Co. 1970, 1975).

For health and safety reasons, naled and dichlorvos should never be transferred to containers in which they could become confused with foods, beverages, drugs, etc. Containers should always be clearly labeled. They should be stored in a secure, locked area away from food.

Neither naled nor dichlorvos requires a Class B Poison label, and both are exempt from Department of Transportation packaging restrictions. Both can be shipped in DOT 6 D steel drums with polyethylene inserts (Shell Chemical Co., 1973 a, 1976; Chevron Chemical Co., 1976).

f. Disposal Methods

a. Fire Retardants

If disposal is necessary, high temperature incineration with adequate scrubbing of the acidic gases formed is recommended (Stauffer Chemical Co., 1975). However, Stauffer Chemical Co. (1975) does attempt to recycle any unwanted phosphates by reprocessing. Those which are not recycled are sometimes combined with other phosphorus-containing wastes in a central disposal pit. The accumulated wastes in some cases may be sold for use as fire retardants in railroad ties.

b. Insecticides

Several alternative methods are available for disposal of unwanted pesticides. The U.S.E.P.A. (1974) recommends that whenever possible the pesticide be used up according to label directions. When necessary, incineration is considered the primary disposal method. Incinerators must be capable of operating at a temperature and dwell time which will completely destroy all the pesticide. Scrubbing equipment must remove hydrogen halides and other gases, to meet emission requirements of the Clean Air Act.

Alternative disposal practices include burial of the pesticide in a specially designated land fill or disposal by soil injection. Chemical degradation (hydrolysis) is recommended prior to landfilling.

Containers should be destroyed after use. The recommended procedure is to rinse the container with an appropriate solvent, punch holes in the container, and bury it in a manner that the pesticides will not pollute ground or surface water, or to burn the container in accordance with state and local regulations (U.S.E.P.A., 1974; Chevron Chemical Co., undated, a, b).

4. Emergency Procedures

a. Fire Retardants

Procedures for emergency action are specifically concerned with fire and human health hazards (Stauffer Chemical Co., 1972 a, b; 1973 a, b). Tris(haloalkyl) phosphates are not immediate fire hazards, since the products are self-extinguishing once the source of ignition is removed. If fire does occur, the vapors will contain the highly toxic fumes of phosphorus oxides and hydrogen halides. In case of fire, it is recommended that the source of ignition be removed or the fire cooled with water. Dry powder or carbon monoxide are alternative measures (Stauffer Chemical Co., 1972 a, b; 1973 a, b).

The following first aid measures are recommended (Stauffer Chemical Co., 1972 a, b; 1973 a, b):

Ingestion - Induce vomiting

Eye contact - Flush the eyes with large quantities of water for a minimum of 15 minutes

Skin contact - Immediately flush affected areas with water. Do not attempt to neutralize with chemical agents.

b. Insecticides

In case of an insecticide spill, the United Parcel Service (1974) recommends that all cleanup personnel wear protective clothing and that the vehicle or facility affected should be hosed down with water. The waste liquids should not be allowed to enter sewer systems. The area should then be dried with a commercial non-organic drying agent.

First aid for contact with skin or eyes was discussed previously (See p. 74). In case of human poisoning, the recommended antidotes are atropine or 2 PAM (Chevron Chemical Co., undated a and b).

5. Current Controls

a. Fire Retardants

There was no specific information in the literature on controls for tris(haloalkyl) phosphates.

b. Insecticides

Air pollution problems can result from vapors or from airborne dust formulations of insecticides. Sittig (1971) considers the dusts to be the greater health threat. According to Sittig (1971), the largest sources of emissions result from crushing and grinding processes in formulating dusts. Other sources of dusts include conveyers, blenders, storage hoppers, and packaging apparatus.

Control of the insecticide dusts and vapors consists of collection through hood and ventilation equipment followed by treatment. To prevent occupational health hazards, Sittig (1971) notes that sources of dust and vapors should be enclosed or tightly hooded. He recommends that ventilation rates for crushers and mills should be 400 fpm or higher. For other operations, hoods should be ventilated at 200 to 300 fpm.

Air pollution control for the collected dusts is achieved by filtering through cloth bags. With high through-puts, a conventional bag house can be used (Sittig, 1971).

With vapor phase insecticides, air pollution control requires scrubbing. Sittig (1971) describes the use of a scrubbing tower (14 cubic foot volume) packed with 1 inch intalox saddles to 4½ feet high. Water rate through the tower is described as 20 gpm.

No specific recommendations for the treatment of liquid wastes containing dichlorvos or naled were found. Liquid effluents containing organophosphate insecticide wastes have been successfully treated by chemical hydrolysis or with activated sludge (Atkins, 1972; Lawless et al., 1972; Lue-Hing and Brady, 1968).

E. Monitoring and Analysis

1. Analysis

Although the literature contains extensive information on analytical methods for organophosphate insecticides, including naled and dichlorvos, rather limited data is available on haloalkyl phosphate fire retardants. Since the two groups of haloalkyl phosphates possess similar physical and chemical characteristics, some of the analytical techniques developed for the insecticides could be applied to the fire retardants. This section emphasizes the analytical methods which have been or could be applied to the fire retardants. However, the pesticide analytical methods will be briefly reviewed first.

a. Pesticides

Residue analysis generally consists of three stages: (1) collection; (2) sample preparation; and (3) analytical measurement (Van Middelem, 1963; Osadchuk et al., 1971). Sources sampled for haloalkyl phosphate pesticide residues include ambient air, water, soil, food, polyvinyl chloride resin, crops, and animal tissues (Van Dyk and Visweswariah, 1975; Wiersma et al., 1972 a, b; Shell Chemical Co. 1971a, 1973b; McCully, 1972; Burchfield et al., 1965). The collected sample should be kept at cold temperatures during storage periods to prevent pesticide degradation (Van Middelem, 1963).

Collection methods developed for haloalkyl phosphate insecticides have varied considerably; many of the techniques could be applied to fire retardants. Water samples may be collected in all glass containers for subsequent work-up in the laboratory (Zweig and Devine, 1969; [illegible] et al., 1973). Large volumes of water have been sampled by passing the water at a known rate through a suitable adsorption column (Hindin 1967; Hindin et al., 1964). Van Dyk and Visweswariah (1975) have reported that air has been sampled for organophosphates by the use of impingers, scrubbers and adsorption columns. The efficiency of collecting air samples can be increased by lowering column temperature. They noted that particulate filtering yields poor results, since the particles collected on the filter can either desorb or adsorb pesticides. Prager and Deblinger (1967) describe a gas chromatographic unit for continuously monitoring airborne phosphate insecticides. However, the technique measures total phosphorus-containing compounds rather than a specific substrate. Solid samples, including foods, plant and animal tissues, and resins, are usually chopped-up and then extracted with a suitable solvent, e.g.,chloroform, ethyl acetate, or hexane (Shell Chemical Co., 1964, 1973b; Chevron Chemical Co., 1973).

Sample preparation usually consists of extracting the substrate of interest into an appropriate solvent, removing interfering substances and sometimes concentrating the solution containing the compound of interest. Gas chromatography, which is the most sensitive method available for haloalkyl phosphates, is very sensitive to interferences. Interferences can foul equipment, overload the column or detector, or cause peak tailing, or might inadvertently be measured along with the substance of interest. Zweig (1970) and McCully (1972) suggest extraction of the pesticide into a suitable solvent followed by a chromatographic clean-up procedure. They favor acetonitrile as the solvent and suggest acetonitrile-petroleum ether portioning if the removal of lipids is necessary. Column chromatography is then suggested using Florisil, Celite, alumina, and aluminosilicate, or charcoal as the adsorbant (Watts et al., 1969; Zweig, 1970; McCully, 1972).

Table 31 lists the lower detection limits for some common methods of dichlorvos and naled analysis. With the exception of enzymatic techniques, these methods could be used to analyze the fire retardants.

In choosing a method, one must consider the residue concentration, the purpose of the work, and the cost for equipment and manpower. For example, gas chromatography combined with mass spectrometry is unexcelled for unequivocal identification and measurement of low concentrations of residues in environmental samples. The equipment and operating costs are, however, relatively high. When multiple samples of a known haloalkyl phosphate in the absence of interferences must be quantitatively analyzed, a total halide or total phosphorus determination would be a more efficient technique (Ott, 1975). The haloalkyl phosphate fire retardants are not sufficiently active esterase inhibitors for successful use of an enzyme inhibition technique.

Table 32 lists some of the many techniques used to analyze naled and dichlorvos.

Table 31. Lower Limit of Detection for Analysis of Haloalkyl Phosphates

Analytical Technique	Detected	Lower Limit of Detection	Reference
Gas Chromatography			
Electron capture detector	Cl, Br, P	0.1 - 1 ng	Zweig; 1970;
Sodium thermionic detector	P	1.0 - 10 ng	Westlake and
Flame photometric detector	P	1 ng	Gunther, 1967;
Microcoulometric detector	Cl, P	10 - 100 ng	McCully, 1972
Thin-layer chromatography			
Silver nitrate spray detection	Cl, Br		Wise, 1967;
Acid-molybdate spray detection	P		Watts, 1967;
Esterase spray detection	Esterase inhibition	5 ng	Mendoza and Shields, 1971
Infrared spectrometry		10 μg	Widmark, 1971
Mass spectrometry		10 ng	Widmark, 1971
Elemental analysis			
Molybdenum complex	P	40 ng	Kirkbright, *et al.*,1971
Specific ion electrode	Cl, Br	100 ng	Buchler, 1971; Thomas Co., 1974
Enzymatic analysis	Esterase inhibition	5 ng	Mendoza and Shields, 1971; Burchfield *et al.*, 1965

Table 32. Summary of Analyses of Dichlorvos and Naled

Reference	Sample Source	Analytical Technique
Giuffrida, 1964	Food	GC-AFD
El-Refai and Giuffrida, 1965	Food	GC-AFD
[illegible] et al., 1967a, b	Food and river water	GC-AFD
Minett and Belcher, 1969	Food	GC-AFD
Beckman and Garber, 1969	Food	GC-AFD
[illegible], 1971	Crops	GC-AFD
Machin et al., 1973	Blood	GC-AFD
Chevron Chemical Co., 1974	Plant tissue and milk	GC-AFD
Shell Chemical Co., 1973b, 1971a	Air, food, animal tissues, formulated products	GC-AFD
Askew et al., 1969	River water, sewage effluent	GC-AFD TLC-Molybdate spray
Schultz et al., 1971	Tissues and urine	GC-AFD and GC-ECD
Crisp and Tarrant, 1971	Crops	GC-AFD
Ives and Giuffrida, 1969	Food	GC-FPD
Scolnick, 1970	Experimental mixture	GC-chemical ionization detector sensitive to phosphorus
Boone, 1965	Food	GC-microcoulometric detector
Bache and Lisk, 1966	Food	GC-microwave powered detector set selective for phosphorus
Pardue, 1971	Experimental mixture	GC-ECD
McKinley and Read, 1962		PC-Esterase spotting
Getz and Friedman, 1963		PC-Esterase spotting
Mendoza and Shields, 1971		TLC-Esterase spotting
Beck and Sherman, 1968	Animals	TLC-$AgNO_3$ spotting
Muthu et al., 1973	Air	Enzymatic inhibition
Ott and Gunther, 1966	Food	Enzymatic inhibition
Heuser and Scudamore, 1966	Air	Enzymatic inhibition
Leegwater and Van Gend, 1968	Food	Enzymatic inhibition

GC -- Gas chromatography
AFD -- Alkaline flame detector
ECD -- Electron capture detector
PC -- Paper chromatography
TLC -- Thin-layer chromatography

Gas chromatography is the most frequently chosen technique for measuring low residue levels in samples from the ambient environment where related materials might be present. Glass columns are recommended over stainless steel or other metal tubing, because metals can decompose halogenated hydrocarbons (Zweig, 1970). A polar liquid phase such as one of the silicone oils (e.g., SE 30 or DC-200) is recommended for phosphate insecticides (Zweig, 1970). The alkaline flame detectors (AFD), which are also known as thermionic detectors, are an excellent choice for the haloalkyl phosphates. Advantages include their high specificity and sensitivity for phosphorus over other elements, their low detection limits, and the excellent linearity of their response curves at lower limits of detection (Westlake and Gunther, 1967; Zweig, 1970; Widmark, 1971; McCully, 1971, 1972). Other phosphorus-specific detectors have also been used successfully. These detectors, such as flame photometric detectors and microwave powered detectors, filter out all wavelengths other than those specific for phosphorus. For example, the flame photometric detector filters out irradiation other than the phosphorus-specific wavelength, 526 nm (Zweig, 1970). Electron capture detection is not recommended for naled and dichlorvos, although it does permit detection of low concentrations. Its disadvantages include its high potential for inadvertent measurement of other substrates and its lack of a linear response curve at low concentrations.

Unequivocal gas chromatographic analysis requires some confirmation that the observed peak corresponds to only the compound of interest. Some chromatographic techniques have been used as confirmation (e.g., by retention time on two different packing materials). However, confirmation by a totally independent analytical technique is preferred. Mass spectroscopy in conjunction with gas chromatography has often been the method of choice (Widmark, 1971; Biros, 1971). Gas chromatography combined with infrared spectroscopy can also be used, but this technique requires some three orders of magnitude higher concentration of the substrate (Widmark, 1971).

TLC has also been used for quantitative analysis. Getz (1971) suggests that optical techniques are the most sensitive quantitative method.

b. Fire Retardants

Table 33 lists methods by which DBPP has been analyzed. It is the only haloalkyl phosphate fire retardant for which analytical techniques capable of measuring low concentrations have been developed and reported in the literature.

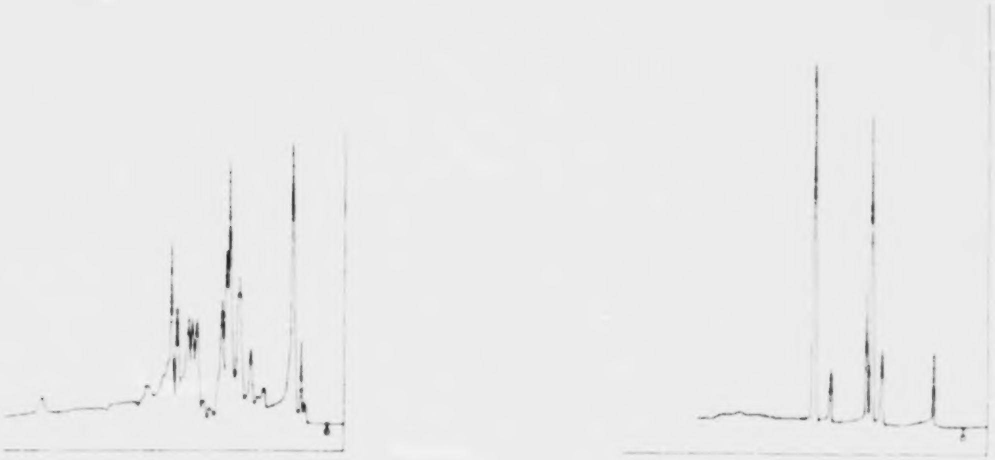
Gutenmann and Lisk (1975) used a colorimetric phosphomolybdate complex technique for quantitative analysis of aqueous DBPP. The water sample was either evaporated to dryness (This work-up procedure is susceptible to many phosphorus interferences) or DBPP was partitioned into benzene and the benzene stripped off. The detection method consists of hydrolysis of the ester to yield ortho phosphoric acid, subsequent preparation of the phosphomolybdate complex and finally colorimetric measurement of its concentration. Hydrolysis of the ester required a four hour reflux with hydrobromic acid.

Morrow and coworkers (1975) determined DBPP in treated fiber by bromide analysis following a benzene-hexane extraction. The benzene-hexane solution of DBPP was burned in oxygen, and the bromide was collected and determined by specific ion electrode. Concentration of parts per million based on original fiber were reported (See Table 30, p. 66).

Table 33. Summary of Analyses Techniques for Tris(2,3-dibromopropyl) Phosphate

Reference	Sample Source	Sampling Technique	Analytical Technique
Cope, 1973	Treated fiber	Pyrolysis	Gas chromatography-flame photometric detector
Morrow *et al.*, 1975	Treated fiber	Extracted by organic solvent	Bromide electrode
Gutenmann and Lisk, 1975	Treated fiber	Extracted with water	Colorimetric measurement of phosphomolybdate complex

Cope (1973) examined the gas chromatograph of DBPP pyrolysate (Figure 6). Samples of DBPP reagent and DBPP on polyester were pyrolyzed at 400° C and passed onto the g.c. column. The resulting chromatograms are rather complicated, and the method does not appear to be suitable for identification or measurement of ambient levels.



(a) (b)

Figure 6. Gas Chromatographs of Tris(2,3-dibromopropyl) Phosphate Reagent (a) and on Polyester (b) (Cope, 1973)

Conditions:
Injection - Pyrolysis at 400° C
Column - 6' stainless steel packed with 5% OV-1 silicone on 60/80 Chromosorb
Temperature - 50 to 180° C at 10°/minutes
Detection - flame photometric

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Although gas chromatography is theoretically the most sensitive technique for analyzing haloalkyl phosphate flame retardants, their relatively low thermal stabilities and vapor pressures might limit the application of the technique. In gas chromatography the sample must be vaporized in the injection port and then separated into the individual components on the chromatographic column. Naled does exhibit minor degradation to yield dichlorvos during chromatographic analysis (Chevron Chemical Co., 1973). Haloalkyl phosphate fire retardants are thermally less stable and have lower vapor pressures than naled or dichlorvos. Thus, it might not be possible to pass tris(haloalkyl) phosphates through a gas chromatograph at temperatures at which they are stable.

Thin layer chromatography should be effective for analysis of haloalkyl phosphate fire retardants. TLC conditions discussed for dichlorvos and naled probably would be applicable to fire retardants. Silver nitrate techniques are suggested for their spotting. Esterase and phosphomolybdate sprays are not expected to be useful. Acid hydrolysis, which is necessary for the phosphomolybdate technique, would probably be too slow.

2. Monitoring

CEP has been listed as an organic compound found in U. S. drinking water (WSRL, 1975). Except for this listing, no monitoring study has listed any of the six haloalkyl phosphates discussed in this report.

Several groups have monitored for ambient pesticides, including organophosphates. The following studies, which used gas chromatography with alkaline flame detection, did not list naled or dichlorvos: Surface Waters - Schulze and coworkers (1973),Zweig and Devine, 1969; Ground Water - Schulze and coworkers (1973); and Soils - Wiersma and coworkers (1972 a, b), Crockett and coworkers (1974). The investigation by Zweig and Devine (1969) was the only study to specifically confirm their absence.

III. Health and Environmental Effects

A. Environmental Effects

1. Persistence

a. Biological Degradation, Organisms, and Products

Microbial degradation of haloalkyl phosphates has been the subject of only a few reported studies. Among the compounds on which some biological fate-related information is available are: dichlorvos, an organophosphorus insecticide, and tris(2,3-dibromopropyl) phosphate, a fire retardant.

In view of the fact that dichlorvos reaches soil most often as a result of direct application, its fate in soil has received the most attention. Matsumura and co-workers (Matsumura and Boush, 1968; Boush and Matsumura, 1967) reported that *Trichoderma viridis*, a soil fungus, and *Pseudomonas melophthora*, an insect symbiote, had the ability to degrade dichlorvos. The fungus was isolated from soil which had been heavily contaminated with a number of insecticides. The bacterium was obtained from the larvae of the insect, apple maggot. In the degradation studies C-labelled dichlorvos (0.22ppm) was incubated with the organism in a liquid medium containing yeast extract and mannitol as nutrient source. The criteria used for degradation was conversion of the organophosphate to water-soluble metabolite(s). The authors reported nearly 85% conversion to water-soluble metabolites by the bacterium and nearly 95% conversion by the fungal culture. Although the breakdown of dichlorvos by the insect symbiote may be important from the point of view of the protective mechanism of the host, the environmental significance of such breakdown appears to be very limited. The results of the study may suggest, however, that other more environmentally significant

Pseudomonas sp. may also have the potential to attack this compound.

The bacterial attack on dichlorvos gave rise to two water-soluble metabolites, which separted when thin layer chromatography was used. The number of metabolites formed in the fungal cultures was not determined. No attempts were made to identify the metabolites of dichlorvos. It is generally assumed that conversion of a compound to water-soluble metabolites implies the compound is biodegradable. This is, however, not always true, and, unless the identity of the metabolites is known, it remains uncertain if the metabolites may be more toxic and/or persistent than the parent compound.

A bacterium isolated from mosquite breeding waters (where the organophosphorus pesticide had presumably been applied) and later identified to be *Serratia plymuthica*, was also reported to catalyze the breakdown of dichlorvos (Hirakoso *et al*., 1968). It was noted that the products of breakdown by *S. plymuthica* were devoid of pesticidal activity. Other details of the study are not available.

In an effort to ascertain the contribution of biological and non-biological agents to the degradation of dichlorvos in soil, Getzin and Rosefield (1968) studied pesticide degradation in non-sterile, gamma radiation-sterilized, and autoclaved soil. The organophosphate was degraded nearly 100% in non-sterile soil and nearly 88% in the gamma-irradiated soil, which suggested that microorganisms were partly responsible for the degradation process. In the irradiated soil, the breakdown was attributed to a non-viable, heat-labile substance (suspected to be cell-free enzymes). This conclusion was based on the observation that in heat-sterilized soil (autoclaved soil), degradation of dichlorvos was only 17%. The method of assay of insecticide residue in soil in this study involved extraction with hexane, followed by measurement with a gas liquid chromatograph equipped with a phosphorus detector. The chemical nature of the breakdown products was not determined.

The ability of a mixed culture of microorganisms present in raw sewage to degrade the flame retardant DBPP was evaluated by Kerst (1974) in a shake flask test (Soap and Detergent Association, 1965). Sewage microorganisms, following acclimation by two 72-hour adaptive transfers, were incubated in SDA basal medium (containing 0.3 g/1 yeast extract) with DBPP. A flask to which linear alkylbenzenesulfonate (LAS) had been added was also incubated simultaneously and served as a positive control. Since DBPP is soluble to only 1.5 ppm, an increase in the bromine content of the aqueous phase in excess of the solubility of DBPP was presumed to be due to bromide release from DBPP degradation. The total bromine content was estimated using neutron activation analysis. Employing this criteria, the authors reported that slow degradation of DBPP was occurring and that nearly 0.3-0.5% of the total added DBPP (calculated from the bromine equivalents of DBPP) had been degraded after an incubation period of 5-15 days. (See Table 34.)

However, very little can truly be concluded from the data because the observed change of bromine concentration can be attributed to a variety of causes. For example, an increase in the solubility of DBPP will also result in increased bromine levels in the liquor. In the inoculated samples, the bacterial metabolism of the basal medium may cause medium compositional changes which may subsequently affect the solubility of DBPP.

Table 34. Biodegradability of Tris(2,3-dibromopropyl) Phosphate (DBPP) in Shake Culture Test (Kerst, 1974)

	DBPP added (mg)	Total reaction volume (ml)	% DBPP presumed to be degraded		
			5 days	10 days	15 days
Blank	2300	2020	0.47	0.68	0.88
Innoculated sample	2300	2020	0.78	1.13	1.42
Difference between blank and innoculated sample	--	--	0.31	0.45	0.54

*On the basis of the increased bromine content of the aqueous phase (DBPP is soluble to only 1.5 ppm in water), DBPP content calculated from the theoretical value of 6.9 g bromine per 10 gm DBPP.

Slow or no biodegradability of DBPP has also been suggested by McGeehan and Maddock (1975) who state that DBPP will tend to bioaccumulate in trash dumps and other disposal sites.

In summary, the persistence of haloalkyl phosphates in the environment is not well understood. The available information on DBPP and dichlorvos suggests that these compounds may be susceptible to microbial attack to some extent. The identity of the products or the mechanisms of their breakdown are not known. It is also unclear if the haloalkyl phosphates will undergo only hydrolysis or are susceptible also to further breakdown.

b. Chemical Degradation in Environment

Experimental data on the degradation of haloalkyl phosphates in the environment by chemical agents is not available. The chemical reactions and other characteristics of these compounds in relation to materials such as water, air, etc., have been reviewed in Section I-B, p. 13). Hydrolysis of dichlorvos and naled in aqueous solution is fairly rapid under conditions similar to those found in nature. Dichlorvos also decomposes rapidly when sorbed onto solid carriers, even when the carriers have been dried (Attfield and Webster, 1966). Getzin and Rosefield (1968) have reported nearly 17% breakdown of dichlorvos in soil in 24 hours by chemical mechanism(s). The fire retardant haloalkyl phosphates have been described to undergo only slow hydrolysis under neutral conditions (Tenneco Chemicals, Inc., undated).

The transformation of haloalkyl phosphates as a result of chemical oxidation in the environment is unlikely except in the case of dichlorvos, which has a double bond. Available information suggests that the commercial haloalkyl phosphates are not photodecomposed by sunlight to any measurable extent (Stauffer Chemical Co., undated, a,b,c,d).

2. Environmental Transport

No experimental work relating to the environmental transport of haloalkyl phosphates has been reported. The fairly low vapor pressure of these compounds (Table 2, p. 4) suggests that they will not rapidly vaporize and distribute through the atmosphere. Mackay and Leinonen (1975) have presented equations which allow estimations of approximate evaporation rates of low water-soluble contaminants from a water body to the atmosphere. Using this approach, the evaporation half-life for haloalkyl phosphates DBPP and dichlorvos for a cubic meter of water would be 59.5 and 2111 hours respectively (See Table 35). Thus evaporation will probably have only a small role in the distribution of haloalkyl phosphates in the environment.

Calculation of the evaporation half-lives for certain low molecular weight chlorinated hydrocarbons for which experimental values are known (Dilling _et al._, 1975) has revealed that the calculated values are in general much longer than the experimental values. (e.g., for methylene chloride, calculated and experimental values are 5.35 hours and 21 minutes, respectively.) In view of this discrepancy, it needs to be emphasized that the calculated half-lives for haloalkyl phosphates should only be relied upon to obtain a rough order of magnitude of their evaporation from water.

No laboratory and/or monitoring studies have been reported which deal with the mobility of haloalkyl phosphates in the aquatic environment. Haloalkyl phosphates in general are sufficiently water-soluble (except perhaps for DBPP) to suggest that at environmentally significant concentrations they will more likely remain dissolved in water rather than

Table 35. Calculated Approximate Evaporation Rates for Haloalkyl Phosphates in an Air-Water System at ~25°C (Method of Mackay and Leinonen, 1975)

Compound	Solubility ($moles/m^3$)	Vapor pressure (atm.)	Henry's law constant ($atm.\ m^3/mole$)	Evaporation half life* (Hours)
DCPP	0.23	1.31×10^{-5}	5.67×10^{-5}	59.5
DBPP	2.1×10^{-3}	2.5×10^{-7}	1.19×10^{-4}	43.1
Dichlorvos	45.24	4.21×10^{-5}	9.3×10^{-7}	2111
Benzene (for comparison)	22.8	12.5×10^{-2}	5.4×10^{-3}	4.81

*For a column of water 1 m^2 in cross section of 1 in depth containing 1 m^3 of water.

be absorbed on particulate matter or sediment. Consequently, these compounds and perhaps also their hydrolysis products may be expected to be transported with water. On the other hand, DBPP is so insoluble in water (1.5ppm) that adsorption to particulate matter and sediment may play an important role in its environmental transport.

3. Bioaccumulation and Biomagnification

Laboratory studies on the bioaccumulation and biomagnification potential of haloalkyl phosphates are not available. Physical and chemical characteristics of their molecules may allow prediction of their behavior to some extent. Accumulation of a chemical occurs when the chemical is taken into biological material faster than it is eliminated. The appreciable water solubility of many haloalkyl phosphates (CEP, CPP, DCPP and dichlorvos), coupled with their susceptibility to biological and/or chemical hydrolysis whereby they may be converted to even more water soluble compounds (See Section III-A-1), suggests that they will have relatively low bioconcentration potential. Tris(2,3-dibromopropyl) phosphate, on the other hand, has very low water solubility and it may be bioconcentrated.

Biomagnification refers to concentration of a compound through the consumption of lower organisms by higher food chain organisms with a net increase in tissue concentration (Isensee et al., 1973). Metcalf and Lu (1973) have noted that the biomagnification potential of the chemicals evaluated in their model aquatic ecosystem showed a relationship with water solubility; they described a regression equation for the line fitted by the method of least squares. Using this relationship, the biomagnification potential for haloalkyl phosphates has been calculated and the values are given in Table 36. From the data, it appears that haloalkyl phosphates in general will not biomagnify to a significant extent in the food chain organisms. Some biomagnification in the food chain, however, may be possible in the case of DBPP.

Table 36. Biomagnification Potential of Haloalkyl Phosphates (Calculated from the Regression Equation of Metcalf and Lu (1973))

Compound	Log Water Sol., ppb.	Biomagnification potential, Fish $\left(\frac{\text{Concn. in Fish}}{\text{Concn. in Water}}\right)$
DBPP	3.17	338
CEP	6.84	1.7
CPP	6.0	5.63
DCPP	5.0	24.0
Dichlorvos	7.0	1.3
DDT (for comparison)	0.079	16950

B. Biological Effects

1. Biology

a. Absorption, Transport, and Distribution

i. Tris(haloalkyl) Phosphates

Little information is available on the absorption, distribution, and transport of the tris(haloalkyl) phosphates. Specific information is limited to data on tris(2,3-dibromopropyl) phosphate (DBPP). These data suggest, however, that the tris(haloalkyl) phosphates may not be absorbed and metabolized in the same fashion as dichlorvos and naled.

A study was conducted on the absorption of DBPP in rats and humans by St. John and coworkers (1976). In one portion of the study, 100 mg of pure liquid DBPP was spread on the gauze pad of a 1" bandaid and pressed tightly to an area of shaved skin on a rat's back where it remained for seven days. The bandage was tightly secured with adhesive tape. In the second part of the study, the entire body of a rat was shaved and covered by a close-fitting sleeve of flannel treated with the fire retardant. This exposure was continuous for nine days. Two humans (one adult and one child) were also exposed nightly for seven nights to fire retardant-treated flannel pajamas. Urine samples were monitored for the appearance of a suggested metabolite, 2,3-dibromopropanol, which would have indicated absorption.

Results of the first rat study (with direct application of the chemical) indicated dermal absorption of DBPP had occurred. This absorption process resulted in a slow appearance of the metabolite in urine (See Section III-B-1-b, p. 99). However, in both rats and humans exposed to the fire retardant-treated fabric, the presence of 2,3-dibromopropanol, in either the free or conjugated form, could not be identified in the urine. St. John and coworkers (1976) concluded that if any of the chemical did migrate from the fabric to the skin and was actually absorbed, the resulting amount of urinary 2,3-dibromopropanol was too small to be detected (sensitivity = < 0.4 ppm in the rat and < 0.2 ppm in the humans). Small amounts of the metabolite were isolated in rat urine when the rat was allowed to chew on the fabric. Apparently, sufficient amounts of DBPP were absorbed from the fabric by the oral route. It is not known from the above study, however, whether 2,3-dibromopropanol was the most appropriate metabolite to be monitored. Furthermore, lacking evidence from a study using radiolabeled material, it is difficult to determine, (1) the percent of the applied dose which is actually absorbed, (2) the amount and location of the parent compound and its metabolites in various body tissues, including their time of retention, and (3) the major routes of excretion (i.e. , urinary, fecal, expired CO_2, biliary, etc.).

After oral absorption of DBPP, bromine residues are stored in various body tissues for an extended period. Kerst (1974) determined the distribution of bromine residues after an experiment in which rats were fed 100 and 1000 ppm of the fire retardant in their diet for 28 days. The results (see Table 37) showed that dose-related levels of bromine, expressed as ppm equivalents of the parent compound, remained in the muscle, fat, and liver after the treatment was discontinued. The residue concentrations returned to the control levels by six weeks after discontinuation of the DBPP feeding. The tissue levels of bromine remaining after two weeks indicate storage does occur and suggest the possibility of some cumulative effects. This retention is consistent with the somewhat slow appearance of the brominated metabolite after administration of DBPP, as found by St. John and coworkers (1976). The actual identity of the bromine-containing residues was not determined.

Table 37. Tissue Residue Levels - ppm of Bromine in Tissue (Kerst, 1974)

Withdrawal Time (wks)	Number of Test Animals	Feed Level ppm	ppm of Bromine		
			Muscle	Liver	Fat
0	5	0	1.0	2.4	1.3
0	5	100	6.1	17.1	7.9
0	5	1000	48.2	122.0	55.3
2	5	0	1.1	3.2	1.4
2	3	100	1.9	6.2	1.3
2	3	1000	8.2	23.2	7.7
6	2	0	1.0	2.1	0.7
6	2	100	0.8	2.4	0.6
6	2	1000	0.8	2 3	0.6

ii. Dichlorvos

Dichlorvos is very well-absorbed into mammalian systems by virtue of its high lipid solubility (which enhances oral and dermal absorption) and high vapor pressure (which enhances inhalation absorption). Radiotracer studies have indicated (Gaines _et al_., 1966; Casida _et al_., 1962; Laws, 1966; Potter _et al_., 1973a,b) that dichlorvos, when administered by oral and parenteral routes, can be monitored in the hepatic and systemic circulation within minutes of its administration to various animals. Inhalation exposure to dichlorvos in rats produced a similar pattern of rapid uptake and tissue distribution with elimination being almost complete in less than one hour (Blair _et al_., 1975).

iii. Naled

Being somewhat less volatile and lipid soluble than dichlorvos, naled may not be as readily absorbed. However, when administered orally to the cow, naled followed a pattern of uptake essentially identical to that of dichlorvos (Casida _et al_., 1962). This may be due to its rapid biotransformation to dichlorvos (Menzie, 1969). Peak blood levels were obtained within two hours of treatment, with elimination from the blood being complete after five days.

b. Metabolism and Elimination

i. Tris(haloalkyl) Phosphates

Little information is available on the metabolism of tris(haloalkyl) phosphates. Considering their chemical nature (See Section I-B), these compounds would probably undergo hydrolysis to some extent, although much more slowly than dichlorvos or naled.

Johnson (1965) determined that the glutathione level in female rat livers was not affected by the oral administration (200 g/rat) of either DBPP or CEP. The metabolism of dichlorvos, however, is strongly influenced by glutathione levels in the liver (See Section III-B-1-b-ii, p. 101).

Limited studies on the metabolism of DBPP in rats were conducted by St. John and coworkers (1976). An initial assumption was made that DBPP would be hydrolyzed to an alcohol or acid in the same fashion as organophosphate insecticides. Therefore, DBPP should yield 2,3-dibromopropanol (DBP) as an alcohol hydrolysis product, and subsequently be eliminated in either free form or as a conjugate in the urine.

In order to determine whether the hydrolysis of DBPP to DBP occurred in rat liver tissue, St. John and associates (1976) conducted in vitro studies with the 10,000 x g supernatant fraction of fresh rat liver. This fraction contained both microsomes and soluble enzymes. Their results indicated about a 5% conversion of DBPP to DBP after a 30-minute incubation period, suggesting that DBP may not be a major metabolite of DBPP.

When tested in vivo by exposing rats to concentrated DBPP applied dermally, urinary excretion of DBP and its conjugates was detected. The data in Table 38 reveal that only small quantities of DBP were excreted in the urine. The apparently elevated levels of DBP in later samples are probably due to a concentrating effect produced by a decreased urine output. The investigators verified their analytical methods by treating control urine samples with 5 ppm of DBP. Recovery ranged from 84 to 90% with the limits of detection being 0.4 and 0.2 ppm in rat and human urine, respectively.

Table 38. Concentrations of Free and Conjugated 2,3-Dibromopropanol (DBP) in Rat Urine as a Function of Time After Dermal Application of Liquid DBPP on Day Zero (Modified after St. John *et al.*, 1976)

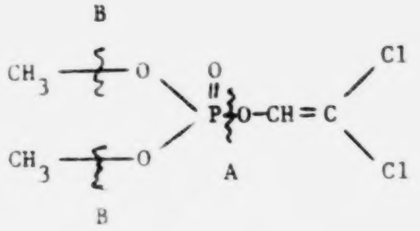
Day	Urine Production (Daily total in g)	Urinary concentration as DBPP (ppm)	
		DBP (free)	DBP (conjugated)
0 (control)	12.2	nd[1]	nd
1	8.8	nd	1.28
2	11.0	0.80	1.17
4	9.2	2.67	2.83
5	6.2	12.81	10.67
7	4.1	1.33	7.63

[1] not detectable

The lack of radiolabeled DBPP prohibited a more quantitative investigation of excretion patterns and the isolation of all biotransformation products. It is apparent from the data which are available, however, that DBPP is probably not metabolized in the same fashion as the insecticidal organophosphate compounds.

ii. Dichlorvos

The pattern of tissue distribution of radioactivity from ^{32}P-dichlorvos is typical of a compound that is rapidly hydrolyzed and excreted (Casida *et al*., 1962). Two major pathways of dichlorvos degradation have been determined, one in which the P-O-vinyl bond is hydrolyzed and the other in which demethylation occurs (Figure 7). Radiotracer studies have indicated that the former is the predominant route (Casida *et al*., 1962; Hutson *et al*., 1971a,b; Hutson and Hoadley, 1972a,b).



A: phosphate-vinyl bond

B: phosphate-methyl bonds

Figure 7. Sites of Metabolic Cleavage of Dichlorvos

Studies on the *in vitro* degradation of dichlorvos in the rat kidney and in whole blood of the rat, rabbit, and human indicated that dichlorvos is very rapidly metabolized (Blair *et al*., 1975). Hodgson and Casida (1962) determined the metabolic pathways of dichlorvos degradation based on *in vitro* studies in the rat (Figure 8).

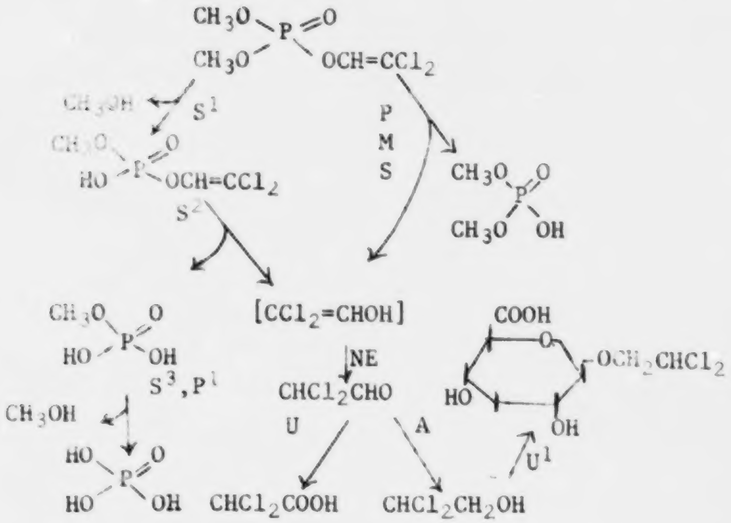


Figure 8. Metabolic Pathways of Dichlorvos in the Rat Based on In Vitro Studies (Hodgson and Casida, 1962)

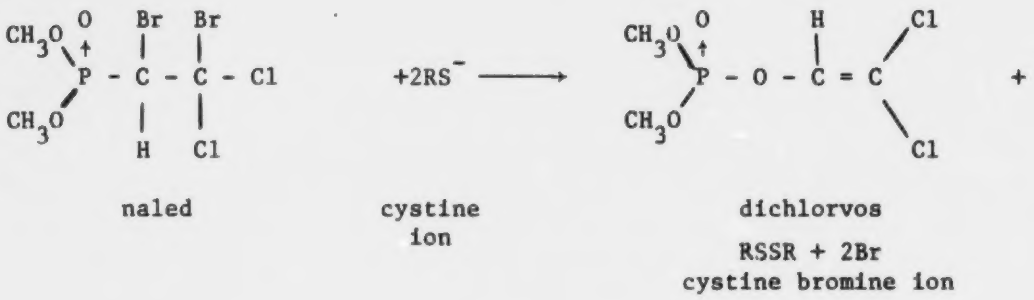
P	Plasma enzyme hydrolyzing dichlorvos to dimethyl phosphate, activators not studied.
P^1	Plasma enzyme hydrolyzing monomethyl phosphate to inorganic phosphate, activators not studied.
S	Soluble liver enzyme hydrolyzing dichlorvos to dimethyl phosphate, activated by Mn^{++}.
S^1	Soluble liver enzyme hydrolyzing dichlorvos to des-methyl dichlorvos, activators not studied.
S^2	Soluble liver enzyme hydrolyzing des-methyl dichlorvos to monomethyl phosphate, activated by 1×10^{-4} M Co^{++}.
S^3	Soluble liver enzyme hydrolyzing monomethyl phosphate to inorganic phosphate, no known activators, inhibited by -- SH inhibitors, pH optimum phosphate, 6.8-7.2.
M	Liver mitochondrial enzyme hydrolyzing dichlorvos to dimethyl phosphate, activated by Ca^{++}.
A	Reduction of dichloroacetaldehyde to dichloroethanol by alcohol dehydrogenase, requires DPNH.
NE	Nonenzymatic.
U and U^1	Pathway probably present, nature of enzymes not studied.

Numerous studies on the in vivo degradation of dichlorvos in animals and man verify that rapid detoxification occurs via hydrolysis of the vinyl-phosphate bond and O-demethylation (Hutson et al., 1971b; Casida et al., 1962; Blair and Rees, 1972; Loeffler et al., 1971; Potter et al., 1973a,b; Page et al., 1971, 1972; Hutson and Hoadley, 1972a, b)

Certain investigators have pointed out that the O-demethylation of dichlorvos in vivo and in vitro is influenced by liver glutathione levels (Hollingworth, 1970; Dicowsky and Morello, 1971; Hutson et al., 1971b). Apparently, glutathione dealkylates dichlorvos by accepting methyl groups in a reaction catalyzed by the enzyme glutathione S-alkyl transferase. Desmethyl dichlorvos emerges as the product of this metabolic reaction. However, Miyata and Matsumura (1972) have presented conflicting evidence which discounts the importance of glutathione-mediated demethylation of dichlorvos.

iii. Naled

Few studies on the metabolism of naled have been conducted. According to Matsumura (1975), naled must be converted in vivo into dichlorvos to cause anti-cholinesterase effects and any resultant toxicity. Kohn (1969) cited unpublished data (Chevron Chemical, no date, c) indicating the degradation of naled to dichlorvos is almost instantaneous and proceeds in the following manner:



Menzie (1969) has presented a scheme of degradation of naled which involves two pathways -- one via debromination and the other in which the phosphate-ethyl bond is cleaved (See Figure 9).

c. Metabolic Effects

1. Cholinesterase Inhibition

Organophosphate chemicals have been widely used as insecticides, nerve gases, and therapeutic drugs primarily because of their pharmacologic properties as inhibitors of cholinesterase. Cholinesterases are enzymes whose function is to catalyze the hydrolysis of acetylcholine, an important neurohumoral transmitter substance, into acetate and choline. In catalyzing the hydrolysis of acetylcholine, cholinesterases are responsible for the termination of action at the neuroeffector junction.

Two types of enzymes catalyze the hydrolysis of acetylcholine: 1) "pseudo" or "plasma" cholinesterase, which is found widely in plasma, liver, gut, and glial cells, and 2) acetylcholinesterase, or so-called "true" cholinesterase, which is present in erythrocytes and also is located within cholinergic nerves and external to the nerve membrane in cholinergic synaptic regions. Plasma or pseudo cholinesterase may catalyze the hydrolysis of many esters, including acetylcholine, succinylcholine, or procaine. It is an important enzyme in limiting the effects of drugs, but not so much in terminating acetylcholine action at nerve terminals. Acetylcholinesterase, on the other hand, is associated with all cholinergic nerves and is relatively specific for acetylcholine. There is according to Casida (1973) "as yet no clear indication that inhibition of cholinesterase other than acetycholinesterase is responsible for significant physiological disruptions in poisoned animals."

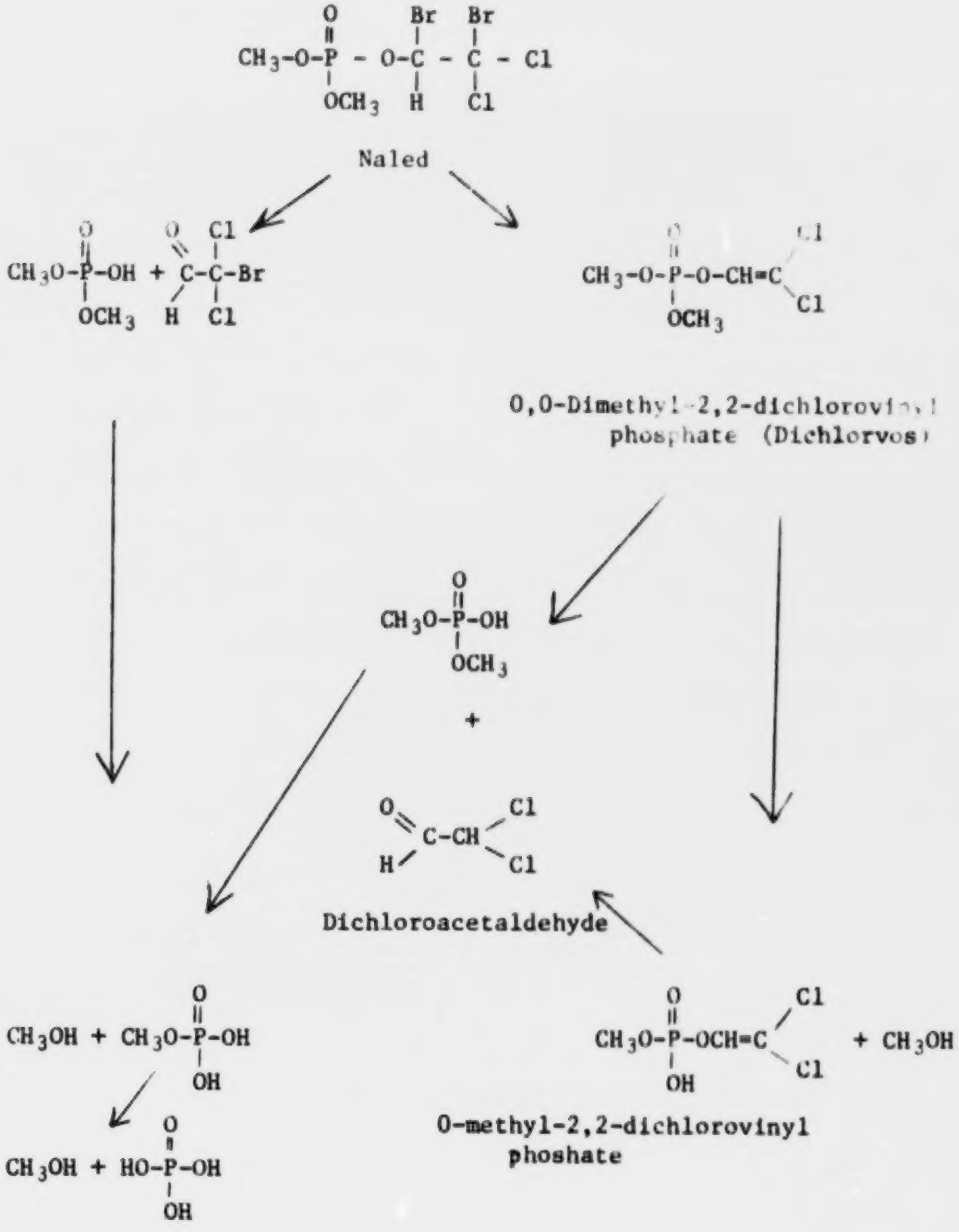

Naled
O,O-Dimethyl-2,2-dichlorovinyl phosphate (Dichlorvos)
Dichloroacetaldehyde
O-methyl-2,2-dichlorovinyl phoshate

Figure 9. The Major Pathways of 1,2-Dibromo-2,2-dichloroethyl Dimethyl Phosphate (Naled) Metabolism (Menzie, 1969)

Cholinesterase inhibitors may be either reversible or irreversible in their action. Reversible cholinesterase inhibitors form a dissociable complex with the enzyme, and inhibition disappears with removal of the drug from the environment. Irreversible inhibitors, which include the organophosphates, form a covalent bond between the inhibitor and esteratic site of both cholinesterase and acetylcholinesterase. Phosphorylation of the esteratic site produces a stable bond between inhibitor and enzyme and results in a very slow regeneration of enzyme activity. In fact, phosphate appears to be more firmly attached to the enzyme with time and results in an "aging" phenomenon such that effects are more easily reversed shortly after poisoning than when a long period has elasped. Furthermore, regeneration of enzyme activity is so slow that recovery usually occurs by de novo enzyme synthesis. However, regeneration rates vary with the inhibitor used.

The pharmacologic effects of acetylcholinesterase inhibition result in the prolonged action of acetylcholine when released by impulse of cholinergic nerves. Effects would be seen on heart rate, body secretions, gastrointestinal tract tone and motility, bladder muscle tone, and skeletal muscle twitch response. In acute overdosage, respiratory embarrassment, shock, diarrhea, and convulsions would result.

Dichlorvos is recognized as an effective inhibitor of cholinesterase in various tissues of animals and man (Van Asperen and Dekhuijzen, 1958; Witter and Gaines, 1963; Ecobichon and Comeau, 1973; Reiff et al., 1971; Braid and Nix, 1969). In summarizing the action of organophosphate chemicals, Reiff and coworkers (1971) indicated that the in vivo inhibition of cholinesterase by compounds such as dichlorvos is directly related to their water-lipid partitioning characteristics and inversely related to the biomolecular rate constant measured *in vitro*. They also found that cholinesterase of the central nervous system is readily accessible by all the organophosphates they studied, regardless of lipophilicity of the compound.

The anticholinesterase activity of the tris(haloalkyl) phosphates has not been extensively studied. It has been demonstrated, however, that DBPP exhibits anticholinesterase effects in goldfish (Gutenmann and Lisk, 1975). The activity of DBPP was measured to be about 16% of that of an equimolar concentration of the insecticide, Tetram [0,0-diethyl-S-(beta diethylamino) ethyl phosphorothiolate]. The anticholinesterase activity of Tetram at a 3×10^{-5} M solution was 0.68 optical density units per minute at 412 $m\mu$ (measured by the method of Ellman *et al.*, 1961).

ii. Alkylating Effects

It is well known that the ability of certain chemicals to cause spontaneous alkylation of biologically-important molecules has resulted in carcinogenesis and mutagenesis. The alkylating properties of the organophosphates are discussed in Section I-B (p. 13) of this report.

From a biological standpoint, the importance of dichlorvos as an alkylating agent is questionable. Having two electrophilic centers of reactivity, the phosphoryl ("hard") groups and the methyl ("soft") groups, dichlorvos will react with nucleophilic groups of biological molecules which are "hard" and "soft," respectively (Bedford and Robinson, 1972). However, spontaneous alkylations (i.e., reactions not enzyme-mediated) proceed at a rate which is extremely slow when compared to enzymic reactions. Therefore, the rapid enzymic hydrolysis of dichlorvos by esterases of the spleen, kidney, blood, and liver would result in a very short biological lifetime in mammals, and consequently little opportunity to produce deleterious alkylations (Bedford and Robinson, 1972).

The fire retardant haloalkyl phosphates, being hydrolyzed more slowly than the organophosphate insecticides (See Section I-B, p. 13), might reasonably be assumed to have greater biological alkylating ability. These compounds have not been tested in biological systems, however.

2. Toxicity and Clinical Studies in Man

a. Occupational and Accidental Exposures

i. Tris(haloalkyl) Phosphates

Ingestion of the fire retardant haloalkyl phosphates has been associated with the development of toxic symptoms in humans. Deaths from accidental exposure to any of these compounds have not been reported, however. Stauffer Chemical Co. (undated, a, 1972a, 1973a,b) reported that ingestion of DBPP, CEP, and DCPP may cause some abdominal discomfort and irritation of the gastrointestinal tract. Ataxia and central nervous system depression may occur from ingestion of DCPP, but no human poisonings have been reported (Stauffer Chemical Co., 1973a). Great Lakes Chemical Co. (1973b) has reported that DCPP has a low order of toxicity by ingestion. Severe cases of poisoning by CEP may lead to convulsions, central nervous system effects, and cardiac and vascular system depression (Stauffer Chemical Co., undated a, 1972a). The above symptoms are characteristic of those produced by cholinesterase inhibition, and therefore it may be suggested that the toxic action of CEP and DCPP might be due to phosphorylation of cholinesterase enzymes in humans. No information is available, however, to indicate the degree of exposure which may be required to produce toxic effects.

Dermal exposure to the tris(haloalkyl) phosphates apparently produces only minimal adverse effects. Stauffer Chemical Co. (1973b) reported that no sign of skin irritation appeared after contact with DBPP. However, CEP is reported to produce mild skin irritation (Stauffer Chemical Co., 1972a). Great Lakes Chemical Co. (1973b) indicated that DCPP has a low order of toxicity by dermal exposure.

Exposure to the fire retardant haloalkyl phosphates through inhalation apparently does not present a significant acute toxic hazard. Hopf (undated) indicated that DBPP presents a low hazard to health by the inhalation route. Stauffer Chemical Co. (1972a, 1973a,b) reported that no effects are known to occur from exposure to DBPP, CEP, and DCPP, although some non-specific irritation may result.

ii. Dichlorvos

Incidents have been reported where numerous children have been intoxicated by ingestion of dichlorvos from chewing on commercial resin strips (Wolter, 1970; Verhulst, 1970; Gillett et al., 1972). No deaths from such exposures have been reported.

Several cases have appeared in the literature where dermatitis has developed in persons exposed to animals wearing flea collars which contained dichlorvos (Cronce and Alden, 1968).

Numerous incidents involving workers who were occupationally exposed to dichlorvos vapors have been reported (Durham et al., 1957; Stein et al., 1966; Witter, 1960; Menz et al., 1974; Ember et al., 1972; Bellin and Chow, 1974). In nearly all cases, the only consequence of exposure by inhalation was a transient decrease in cholinesterase activity, which did not produce clinical symptoms of any kind. It should be noted that a decrease in cholinesterase activity in erythrocytes of 20 to 25% of pre-exposure levels must be achieved before clinical symptoms appear (Zavon, 1965). Gage (1967) has suggested that a reduction to 70% of normal pre-exposure levels of acetylcholinesterase activity should be considered the biological threshold limit in humans.

iii. Naled

The available evidence indicates that naled may be a serious hazard to humans by accidental overexposure. According to Chevron Chemical Co. (undated a, b), naled in concentrated form (85% pure naled) may be fatal if swallowed. However, no deaths have been reported. Atropine and 2-PAM are listed as antidotes, and thereby indicate that cholinesterase inhibition is the primary mechanism of toxic action.

Reports have been made (Edmundson and Davies, 1967) which suggested that naled has produced occupational contact dermatitis in certain agricultural workers. Chevron Chemical Co. (undated a) has stated that concentrated naled causes skin damage and may be fatal if absorbed through the skin. Pesticide workers who were routinely exposed to vapors of various chemicals, including naled, were found to develop chromosomal aberrations during peak exposure periods (Yoder et al., 1973).

b. Controlled Studies

i. Tris(haloalkyl) Phosphates

Cases have been presented where skin has become sensitized and irritated by flannel materials used in sleepwear which were fireproofed by the Proban method (Martin-Scott, 1966). A controlled patch-testing study using DBPP has been conducted by Kerst (1974) and no primary skin irritation or delayed hypersensitivity was seen. The study involved 22 males and 39 females who were exposed to ten patch tests in a 24-day period. Fifty-two of the 61 starting the study completed the ten patch test series as well as a challenge patch test 14 to 21 days later. In each case, 1.1 gram of the compound was applied to the upper left arm and covered with a patch for 24 hours. At the end of that time period, the site was examined for any reaction. One to three days later another sample and patch were applied until ten consecutive patch tests were completed. Fifty of the 52 completing the test series and the nine who left the experiment showed no adverse reaction to the chemical. One of the two individuals reacting to the treatment developed itching and skin eruptions over his whole body after the seventh application; one month later, after the condition had cleared, a challenge test elicited no adverse effects. The other case, a man known to have some allergies, developed itching and a pruritic plaque of the neck at the sixth application; the testing was stopped, the irritation cleared and no adverse reaction was found after a challenge patch test one month later. Kerst (1974) concluded that these two reactions were unrelated to the test compound, and that no skin irritation or skin fatigue due to DBPP was demonstrated in this study.

Additional studies on the skin sensitizing properties of DBPP were reported by Morrow et al. (1975). In early studies, four of 190 subjects became sensitized when exposed to an experimental fabric containing high concentrations of DBPP. Subsequent studies were conducted in humans by exposing them to a number of test fabrics which contained varying amounts of DBPP (Table 39). One-inch squares of the test fabrics were applied to the arms of male volunteers and to the arms or legs of female volunteers for six days. After a 15-day rest period, 48-hour challenge patches were applied. Skin reactions were recorded at two and six days after the initial application and on removal of the challenge patches. Results from 200 subjects indicated no instance of contact dermatitis.

Table 39. Descriptions of Tris(2,3-dibromopropyl) Phosphate*-Treated Fabrics (Morrow et al., 1975)

1. Woven fabric (4 oz./sq. yd.) from Type 54 Dacron® treated with 10% solution of DBPP* in Triclene® heated to 200°C for 3 minutes, rinsed with Triclene® and laundered at 180°C for 15 minutes. The DBPP* content calculated from x-ray analysis for bromine was 4.6%.

2. Same base fabric and treatment as 1 except that the Triclene® rinse and the laundering were omitted. X-ray analysis for bromine indicated 11.3% DBPP*.

3. Mill print cloth woven from polyester yarns (finishing procedure unknown).

4. Sample 3 scoured five times for 30 minutes at 210°F. (1.4% DBPP* by x-ray bromine analysis)

5. Mill print cloth woven from 100% polyester yarns (finishing procedure unknown).

6. Mill fabric knit from polyester yarns treated with LVT-23P* in dye bath.

7. Mill broadcloth woven from polyester yarns, padded with LVT-23P* and thermally fixed.

8. Mill flannel woven from polyester yarns and treated as 7.

9. Tricot knit from Acele® acetate FLR yarn containing 4.5% spun-in DBPP* and washed to remove processing finish.

10. Tricot fabric equivalent to above except that the DBPP* content of the experimental fiber was 8.0%.

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* Asterisk denotes tris(2,3-dibromopropyl) phosphate, DBPP, and LVT-23P are the same compound.

Human maximization tests for allergic sensitization were conducted by Morrow et al. (1975) according to the method developed by Kligman (1966). The experimental details and results are summarized in Table 40. By varying the percentages of DBPP used for sensitization and challenge, different numbers of subjects were sensitized in each of three experiments.

Table 40. Maximization Tests with Tris(2,3-dibromopropyl) Phosphate (Morrow et al., 1975)

Test Protocol	Test No. 1 Oct. 1967 Du Pont DBPP	Test No. 2 Nov. 1973 LVT-23P	Test No. 3 Mar. 1974 LVT-23P
SENSITIZATION			
Concentration SLS(1) %	5	5	5
Concentration DBPP(2) %	100	20	20
Days Incubation	10	10	14
CHALLENGE			
Concentration SLS(1) %	10	10	1
Concentration DBPP(2) %	25	20	20
RESULTS			
No. Completing Test	24	25	20
No. Sensitized	8	2	2 (+1 Weak)

(1) Sodium lauryl sulfate as aqueous solution.
(2) Vehicle was petrolatum.

The three sensitized subjects from Test No. 3 (Table 40) were rechallenged simultaneously with the eight polyester fabrics treated topically with DBPP as described in Table 39. Their results, as summarized in Table 41, demonstrate that seven of the eight fabrics produced an allergic skin response from one or more of the subjects. Reactions were rated on a 0 to 4 basis, with 2 and above considered to be allergic responses.

Table 41. Challenge of Subjects with Fabrics (72-Hour Occlusive Contact) (Morrow et al., 1975)

	Subject Response 96 Hours After Application					
	Multiple Patch Test*			Patches Applied Singly		
	A	B	C	A	B	C
A. Polyester Fabrics						
1	4	2	±	2	0	1
2	4	0	2	3	2	2
3	4	2	3	3	1	2
4	0	0	0	**	**	**
5	4	1	2	**	**	**
6	4	0	1	**	**	**
7	2	0	0	**	**	**
8	4	2	1	**	**	**
B. Acetate Fabrics						
9	**	**	**	2	±	1
10	**	**	**	2	1	1

* Three nonsensitized controls gave no response when tested with the polyester fabrics in a multiple patch test.

** Not tested.

The degree of allergic reaction was positively correlated [illegible] some extent with the amount of surface DBPP available on the test fabric (Table 42).

Table 42. Correlation of Surface Tris(2,3-dibromopropyl) Phosphate Concentration with Sensitized Panel Response (Morrow *et al.*, 1975)

Fabric No.*	Surface Tris(2,3-dibromopropyl) phosphate	Response of Sensitized Panel (96 Hours After Application)		
		Subject A	Subject B	Subject C
2	70,000	3	2	2
3	37,500	3	1	2
5**	20,000	4	1	2
6**	18,000	4	0	1
8**	5,000	4	2	1
7**	2,000	2	0	0
4**	100	0	0	0
9	80	2	1	1
10	65	2	±	1
1	35	2	0	1

* See Table 39.

** Fabric tested in multiple patch protocol; others tested individually.

Morrow and coworkers (1975) concluded from human maximization tests that DBPP can cause allergic contact sensitization which is dose-related. These investigators have rated DBPP as a low level allergen of Class 1-2, capable of eliciting a sensitization response in small numbers of individuals.

ii. Dichlorvos

In human tests designed to evaluate the anthelmintic efficacy of dichlorvos by oral ingestion, acute doses up to 117.6 mg/kg produced varying degrees of cholinesterase inhibition as the only significant side-effect (Hine and Slomka, 1968, 1970; Cervoni et al., 1968).

Dermal exposure to dichlorvos by humans has resulted in no adverse effects other than slight cholinesterase activity variations (Zavon and Kindel, 1966; Cavagna et al., 1969). Slight skin irritation has also been reported, but no cases of contact sensitization have appeared in the literature.

Numerous controlled studies have been conducted with humans to determine the effects of inhaling dichlorvos vapors (Hunter, 1971; Durham et al., 1959; Tracy, 1960; Zavon and Kindel, 1966; Leary et al., 1971, 1974; Vigliani, 1971; Cavagna et al., 1969, 1970; Schoof et al., 1961; Jensen et al., 1965; Smith et al., 1972; Rasmussen et al., 1963). The only apparent effect of exposure as noted in these studies was on plasma and erythrocyte cholinesterase activities.

iii. Naled

Naled has been found to be a moderate to severe human skin irritant in a number of test situations. Phillips and coworkers (1972) evaluated the primary effects of naled on human skin by several methods: 1) a modified Draize irritation test, 2) a 21-day continuous occlusive patch test at 1% and 10% concentrations, and 3) in 21-day non-occlusive testing. Marked blistering of the skin was produced by undiluted naled in the Draize test and by concentrations above 10% in occlusive patch testing.

3. Effects on Non-Human Mammals

a. Acute Toxicity

i. Tris(haloalkyl) Phosphates

The tris(haloalkyl) phosphates are considerably less toxic than the insecticidal organophosphates by acute exposure (See Tables 44, 45, and 46).

The acute oral LD_{50} for DBPP in rats has been reported by Hopf (undated) to be 590 mg/kg. At this dose level, DBPP could be considered a moderately-toxic poison. The results of Shelanski and Moldovan (1972), however, indicated that the oral LD_{50} for DBPP was greater than 5 gm/kg of body weight.

A study on the acute oral toxicity of DBPP in rats has been published by Kerst (1974) which supplies dose-response data and provides some indication of biological sensitivity in the animal population. The results of this study agree with the oral LD_{50} for DBPP in rats reported by Shelanski and Moldovan (1972) and do not confirm the LD_{50} figure of Hopf (undated). Male albino Spartan rats (five per group) were tested at five different dosage levels. The animals were fasted overnight and given 10 ml/kg of a DBPP solution suspended in propylene glycol. The dose-response data are shown in Table 43. The LD_{50} over a 14-day observation period was determined to be 5.24 g/kg. All of those dosed at 1.98 or 3.15 g/kg, except one at the lower dose, showed normal weight gains throughout the 14-day period. The survivors in the 5.00 and 7.94 g/kg dosage groups had less than normal body weight gain.

Additional data on the acute toxicity of the fire retardant haloalkyl phosphates have been reported. The oral LD_{50} of DCPP in

Table 43. Dose Response Data for Male Spartan Rats Given Acute Oral Doses of Tris(2,3-dibromopropyl) Phosphate (Kerst, 1974)

No. Dosed	Dosage Level (g/kg)	Mortality (No. Dead/No. Dosed)
5	1.98	0/5
5	3.15	0/5
5	5.00	3/5
5	7.94	4/5
5	12.50	5/5

rats was given as 2830 mg/kg of body weight (Sanderson, 1975; Stauffer Chemical Co., undated, b). The LD_{50} in rats for CEP (route unknown) was reported to be 521 mg/kg of body weight (Sanderson, 1975). Stauffer Chemical Co. (undated, a) has indicated that the oral LD_{50} of CEP in the rat is 1230 mg/kg of body weight, with a confidence interval of 930 to 1630 mg/kg. Smyth and co-workers (1951) determined the oral LD_{50} of CEP in rats to be 1410 mg/kg of body weight, with 95% confidence limits of 960 to 2080 mg/kg.

When applied dermally to experimental animals, the tris(haloalkyl) phosphates apparently do not produce a significant toxic response. The acute dermal LD_{50} in rabbits for DBPP is greater than 2 gm/kg of body weight (Shelanski and Moldovan, 1972). Kerst (1974) exposed male and female New Zealand white rabbits to DBPP, applied either to the intact or abraded skin of the shaved back. The treatment area was occluded for 24 hours, followed by removal of the bandages and washing of the skin with water. Observations were made for a 14-day period after the initial treatment. At dosage levels up to 8 gm/kg of body weight, DBPP failed to produce any mortality or signs of dermal irritation. Fluctuations in body weight of the experimental animals were considered to be within normal limits. DBPP did not irritate the skin when 1.1 gm was applied to the shaved back and flank areas of six albino rabbits (Kerst, 1974). The test material was applied to abraded and intact skin, covered with gauze tape, and remained for 24 hours. Erythema and edema were absent at 24 hours, when the test material was washed from the skin, as well as after 72 hours, when a second observation was made.

The acute dermal LD_{50} for DCPP in rabbits is greater than 15.8 ml/kg of body weight (Stauffer Chemical Co., undated, b). DCPP reportedly produced no skin irritation. Smyth and co-workers (1951) rated CEP as a grade 2 skin irritant in the rabbit (based upon a four point Draize system), indicating a small degree of irritation equivalent to a trace of capillary injection.

Only limited data are available on the acute inhalation toxicity of the tris(haloalkyl) phosphates. Smyth and co-workers (1951) reported that no deaths occurred in rats exposed to saturated CEP vapors in air for a maximum of eight hours.

Eye irritation studies in rabbits have been conducted with DBPP, DCPP, and CEP. Shelanski and Moldovon (1972) and Stauffer Chemical Co. (1973, b) indicated that DBPP is not an eye irritant. Kerst (1974) applied 0.22 gm of DBPP to the eyes of six rabbits and observed no adverse effects at 24, 48, and 72 hours after the initial treatment. Additional reports have stated that no damage to the eyes of rabbits was produced by CEP (Stauffer Chemical Co., 1972a; Smyth et al., 1951). Stauffer Chemical Co. (undated b, 1973a) indicated that DCPP is a mild eye irritant in the rabbit.

ii. Dichlorvos

Several investigators have determined that dichlorvos is highly toxic by oral ingestion, with the acute LD_{50} in rats being less than 100 mg/kg of body weight (Wagner and Johnson, 1970; Mattson et al., 1955; Durham et al., 1957; Gaines, 1960, 1969; Tracy et al., 1960; Laws, 1966; Jones et al., 1968; Pickering and Pickering, 1971; Shell Chemical Co., 1965; See Table 44). Dogs and monkeys have also been shown to suffer severe effects at acute oral doses less than 40 mg/kg of body weight (Snow and Watson, 1973; Snow, 1973; Northway, 1971; Pryor et al., 1970; Wallach and Frueh, 1968). Symptoms of poisoning were usually associated with marked depression of cholinesterase activity.

By dermal exposure, dichlorvos is only slightly less toxic than by oral administration. Data indicate that female rats are somewhat more susceptible than males (Durham et al., 1957; Gaines, 1960, 1969; See Table 45).

Inhalation of air saturated with dichlorvos vapors (concentration > 30 μg/ℓ) proved fatal to rats in 4.8 to 83.0 hours (Durham et al., 1957). More recent studies have shown that exposure of rats to concentrations of dichlorvos up to 90 μg/ℓ for four hours were not lethal (Blair et al., 1975; Shell Chemical Co., 1973a).

Dichlorvos has been tested for toxicity by several parenteral routes in various animals. These results are summarized in Table 45.

A single report by Tracy (1960) stated that the LD_{50} of undiluted dichlorvos when applied directly to the intact eye of rats is 10 mg/kg of body weight. This result indicates an extremely toxic response, and is somewhat inconsistent with the results of toxicity determinations by other routes of exposure. No further details are available to clarify this observation.

iii. Naled

Studies on the acute toxicity of naled have been conducted with variable results. Naled is apparently less toxic than dichlorvos under most circumstances. Oral administration produces greater toxic effects than dermal exposures. Experimental data are summarized in Tables 44, 45, and 46.

iv. 0,0-Diethyl 2-chlorovinyl Phosphate

The limited acute oral toxicity data available on this compound indicate it is highly toxic to rats and mice (Corey et al., 1953; Holmstedt, 1959). The chemical is structurally closely-related to dichlorvos, but is more acutely toxic to rodents. The oral LD_{50} for rats for dichlorvos is between 56 and 80 mg/kg, whereas the oral LD_{50} in rats for 0,0-diethyl 2-chlorovinyl phosphate is 7.0 mg/kg (See Table 44). By subcutaneous injection in rats, this compound was shown to be lethal at 0.2 mg/kg of body weight, with a calculated LD_{50} of 15.5 mg/kg of body weight (Brimblecombe et al., 1971).

Table 44. Acute Oral Toxicity in Mammals

Compound	Organism	No., Sex, Strain, Age, Weight*	Vehicle, Method of Dosing	Dose (mg/kg)	Lethality	Comments	Reference
DBPP, tris(2,3-dibromopropyl) phosphate	Rat	White, albino	N.S.	>5000	LD_{50}		Tenneco Chemicals, Inc., undated
"	Rat	CFE strain, 65-107 gm	Solutions in arachis oil in volumes of 10 to 16 ml/kg administered by stomach tube	590	LD_{50}	Moderately toxic	Hopf, no date
"	Rat	5 male, 5 female albino, Sherman-Wistar strain	By syringe and stomach tube after 24-hour fast	>5000	LD_{50}	At 5000 mg/kg one male and two female rats died within a 14-day observation period	Shelanski and Moldovan, 1972
DCPP, tris(1,3-dichloro-isopropyl) phosphate	Rat	N.S.	N.S.	2830	LD_{50}		Sanderson, 1975; Stauffer Chemical Co., undated b
CEP, tris(2-chloroethyl phosphate	Rat	Male, albino	N.S.	1230 (930-1630)	LD_{50} with 95% confidence limits		Stauffer Chemical Co., undated a
"	Rat	N.S.		527	LD_{50}		Sanderson, 1975
"	Rat			1410 (960-2080)	LD_{50} with 95% confidence limits		Smyth et al., 1951

* Data given when available

Table 44. (cont'd)

Compound	Organism	No., Sex, Strain, Age, Weight*	Vehicle, Method of Dosing	Dose (mg/kg)	Lethality	Comments	Reference
Dichlorvos (0,0-dimethyl 2,2-dichlorovinyl phosphate)	Rat	59, male, white Sherman, adults, 90+ days old, minimum weight - 175 gm	Technical grade (90%) dichlorvos dissolved in peanut oil; administered by stomach tube in volume of 0.005 ml/gm of body weight	32	LD_1**	All deaths occurred within 1 hour of dosing; all survivors recovered within 24 hours	Mattson et. al., 1955
				50	Minimum lethal dose		Durham et al., 1957
				80 (62-104)	LD_{50} in a 14-day observation period (19/20 confidence limits)	Symptoms of poisoning: bulging eyes, excessive lacrimation, salivation, generalized muscle fasciculations and tremors; some had convulsions prior to death	Gaines, 1960, 1969
		80, female, white Sherman, adults, 90+ days old, minimum weight - 200 gm		26	LD_1**		
				38	Minimum lethal dose		
				56 (48-65)	LD_{50} in a 14-day observation period (19/20 condidence limits)		
"	Rat	Female, white Sherman, adults	Pure dichlorvos dissolved in peanut oil; administered by stomach tube in volume of 0.005 ml/gm of body weight	68 (59-79)	LD_{50} (19/20 confidence limits)		Durham et al., 1957
		Female, white Sherman, adults	Technical grade (90%) dichlorvos administered as above	80 (71-90)	LD_{50} (19/20 confidence limits)		

* Data given when available
** Calculated dose to kill one percent of an experimental population

Table 44. (cont'd)

Compound	Organism	No., Sex, Strain, Age, Weight*	Vehicle, Method of Dosing	Dose (mg/kg)	Lethality	Comments	Reference
Dichlorvos (0,0-dimethyl 2,2-dichlorovinyl phosphate)	Rat	Female	100% pure dissolved in water or physiological saline	62 ± 8	LD_{50} value		Tracy et al., 1960
"	Rat	10, male, white Sherman, 350-400 gm	18 mg/ml in vegetable oil emulsion infused at 0.068 ml/min by pump through stomach tube	19		Cholinergic symptoms (about 15 minutes)	Laws, 1966
				47	Lethal	Death within 30 minutes	
"	Rat	N.S.	N.S.	25-30	LD_{50}	"for the more sensitive of the sexes"	Jones et al., 1968
"	Rat	2, female, CFE, 13 weeks old	Dissolved in unspecified solvent	25	Lethal	Death within 30 minutes	Pickering and Pickering, 1971
"	Rat	N.S.	Vapona® 4 resin strips	400 to 1200	LD_{50}	No data supplied on mode of administration	Shell Chemical Co., 1965

* Data given when available

Table 44. (cont'd)

Compound	Organism	No., Sex, Strain, Age, Weight*	Vehicle, Method of Dosing	Dose (mg/kg)	Lethality	Comments	Reference
Dichlorvos (0,0-dimethyl 2,2-dichlorovinyl phosphate)	Mouse	N.S.	N.S.	110	LD_{50}		Hollingworth, 1970
"	Mouse	270 male, 270 female, 10 per group, non-inbred COV:ICR, 19-26 gm	Dissolved in 1% carboxymethyl cellulose in 3 strengths (6, 12, 24 mg/cc by stomach tube	145 135	LD_{50} (males) LD_{50} (females)	Death within 30 minutes, no deaths after 3 hours Symptoms: muscle fasciculations and ataxia within a few minutes; general paralysis and death (depending on dose)	Wagner and Johnson, 1970
"	Dog	N.S.	N.S.	100-316	LD_{50}		Shell Chemical Co., 1966
0,0-diethyl 2-chlorovinyl phosphate	Rat	N.S.	N.S.	7.0	LD_{50}		Corey *et al.*, 1953
"	Mouse	N.S.	N.S.	30.5	LD_{50}		Corey *et al.*, 1953
"	Mouse	N.S.	N.S.	32	LD_{50}		Holmstedt, 1959

* Data given when available

Table 44. (cont'd)

Compound	Organism	No., Sex, Strain, Age, Weight*	Vehicle, Method of Dosing	Dose (mg/kg)	Lethality	Comments	Reference
Naled (O,O-dimethyl 1,2-dibromo-2,2-dichloroethyl phosphate)	Rat	67, male, Sherman	Dissolved in peanut oil, administered by stomach tube	130	LD_1**		Gaines, 1969
				150	Lowest dose to kill a rat		
				250 (219-285)	LD_{50} (19/20 confidence limits)	Among those that died: minimum survival time = 0.2 hours; maximum survival time = 4 days	
"	Rat	Male	N.S.	250	LD_{50}		Standard Oil Co., 1964
"	Rat	Male	N.S.	250-430	LD_{50}		Sósnierz et al., 1971
"	Rat	N.S.	N.S.	410	LD_{50}		Edmundson and Davies, 1967
"	Rat	N.S.	N.S.	430	LD_{50}	"for the more sensitive of the sexes"	Jones et al., 1968
"	Rat	N.S.	Purified naled	430	LD_{50}		Chevron Chemical Co., 1970
"	Dog	N.S.	N.S.	2.5, 7.5		Lowered plasma and erythrocyte cholinesterase activity levels	Hazelton Laboratories, 1958

* Data given when available

** Calculated dose to kill one percent of an experimental population

Table 45. Acute Dermal Toxicity in Mammals

Compound	Organism	No., Sex, Strain, Age, Weight	Vehicle, Method of Dosing	Dose (mg/kg)	Comments	Reference
Dichlorvos (0,0-dimethyl 2,2-dichlorovinyl phosphate)	Rat	110, male, white Sherman, adults, 90+ days old, 175 gm (minimum weight)	Technical grade (90%) dichlorvos dissolved in xylene, administered in 0.0016 ml/kg amounts on shaved back above tail	53	LD_1*	Durham et al., 1957 Gaines, 1960,1969
				75	Minimum lethal dose	
				107 (84-137)	LD_{50} (19/20 confidence limits)	
		50, female, white Sherman, adults, 90+ days old, 200 gm (minimum weight)		24	LD_1*	
				38	Minimum lethal dose	
				75 (59-96)	LD_{50} (19/20 confidence limits)	
"	Rat	Sherman, adults	Dichlorvos dissolved in xylene;			Gaines, 1969
			Rat restrained	132 (113-159)	LD_{50} (19/20 confidence limits)	
			Rat unrestrained	150 (120-188)	LD_{50} (19/20 confidence limits)	
"	Rat	N.S.	N.S.	75-900	LD_{50} range "for the more sensitive of the sexes"	Jones et al., 1968
"	Rabbit	N.S.	N.S.	218	LD_{50}	Shell Chemical Co., 1973a

* Calculated dose to kill one percent of an experimental population

Table 45. (cont'd)

Compound	Organism	No., Sex, Strain, Age, Weight	Vehicle, Method of Dosing	Dose (mg/kg)	Comments	Reference
Naled (O,O-dimethyl 1,2-dibromo-2,2-dichloroethyl phosphate)	Rat	N.S.	N.S.	1100	LD_{50}	Edmundson and Davies, 1967
"	Rat	50, male, Sherman adults	Technical grade (90%) dissolved in xylene, on shaven area of back above tail	200 400 800 (559-1144)	LD_1* Minimum lethal dose LD_{50} (19/20 confidence limits) of those that died: minimum survival time = 0.1 hours maximum survival time = 2 days	Gaines, 1969
"	Rabbit	N.S.	Purified	1100	LD_{50}	Chevron Chemical Co., 1970
DBPP, tris(2,3-dibromopropyl) phosphate	Rabbit	N.S.	N.S.		Primary irritation index of 0.3, a mild irritant	Hopf, no date
"	Rabbit	6, albino	Skin either intact or abraded	N.S.	Not a primary irritant to the skin; no erythema or edema	Shelanski and Moldovan, 1972

* Calculated dose to kill one percent of an experimental population

Table 45. (cont'd)

Compound	Organism	No., Sex, Strain, Age, Weight	Vehicle, Method of Dosing	Dose (mg/kg)	Comments	Reference
DBPP, tris(2,3-dibromopropyl) phosphate	Rabbit	10, albino	Abraded or intact skin	>2,000	No mortalities from a 2000 mg/kg dose on either abraded or intact skin	Shelanski and Moldovan, 1972
"	Rabbit	6, albino	Shaved, abraded, back and flank, covered for 24 hours	1.1 gm	No erythema, edema, or irritation after 24 or 72 hours	Kerst, 1974
"	Rabbit	2 male and 2 female per group, 4 groups, white, New Zealand, 2359 to 2955 gm	One of each per group had skin abraded; all were covered for 24 hours with gauze and Saran wrap	1.00 gm/kg 2.00 gm/kg 4.00 gm/kg 8.00 gm/kg	No adverse signs or deaths at any dose level; dermal LD_{50} >8.00 gm/kg	Kerst, 1974
DCPP, tris(1,3-dichloroisopropyl) phosphate	Rabbit	N.S.	N.S.	715.8 ml/kg	Skin penetration poor, exact LD_{50} not determined	Stauffer Chemical Co., undated b

Table 46. Acute Parenteral Toxicity in Mammals

Compound	Species	Route of Administration*	Dose (mg/kg)	Response	Reference
Tris(2,3-dibromopropyl) phosphate (DBPP)	Mouse	i.p.	300	LD_{50}	Doull et al., 1962
Dichlorvos	Rat	i.v. (femoral vein)	4.4 to 6.4	All rats died between 17 and 31 minutes from initiation of infusion of solution containing 12.5 mg dichlorvos/ml at a rate of 0.0068 ml/minute.	Gaines et al., 1966
"	Rat	i.v. (intestinal vein)	12.5 to 17.0	No deaths resulted from infusion of solution containing 12.5 mg dichlorvos/ml at a rate of 0.0068 ml/minute.	Gaines et al., 1966
"	Rat	i.p.	6	Death within six minutes.	Arthur and Casida, 1957
"	Rat (female)	i.p. (corn oil)	28	LD_{50} for technical grade material.	Casida et al., 1962
"	Rat (male)	s.c.	35	LD_{50}; minimal toxic dose = 0.2 mg/kg	Brimblecomb et al., 1971
"	Rat (female)	s.c.	11.5	LD_{50}; LD_{10} = 10.0 mg/kg, LD_{90} = 13.5 mg/kg	Natoff and Reiff, 1970
"	Mouse	i.p.	60	Approximate LD_{50} through 14 generations of treated mice.	Guthrie et al., 1971
"	Greyhound Dog	i.v.	2.2 to 11.0	Five of the six treated dogs died; one survivor at the 2.2 mg/kg dose level. Symptoms included vomiting, diarrhea, excessive salivation, muscle fasciculations, clonic convulsions	Snow and Watson, 1973
O,O-Diethyl 2,2-dichloroethyl phosphate	Rat (male)	s.c.	15.5	LD_{50}	Brimblecomb et al., 1971

* Symbols: i.p. = intraperitoneal; i.v. = intravenous; s.c. = subcutaneous

b. Subacute and Chronic Toxicity

i. Tris(haloalkyl) Phosphates

A subacute feeding study in male weanling rats was conducted by Kerst (1974) to determine the effects of long-term exposure to DBPP. The rats were fed for four weeks at 100 ppm and 1000 ppm in the diet and sacrificed either at the end of the experimental period or after two or six weeks of recovery. In addition to blood tests and urine analysis, the rat tissues were analyzed for the presence of bromine. (More details on the bromine residues are discussed in Section III-B-1-a-i, p. 96, of this report).

At both dose levels, rats displayed a decreased rate of body weight gain when compared to control animals (Table 47). When animals were treated for 28 days and followed with a two-week recovery period on a normal diet, body weight differences between treated and control animals diminished somewhat (Table 48).

Table 47. Body Weights and Weight Gain of Rats Fed Tris(2,3-dibromopropyl) Phosphate (Kerst, 1974)

Average Individual - Weekly	0 Week	1 Week	2 Weeks	3 Weeks	4 Weeks	Total
Negative Control						
Body Weight (g)	49	80	123	170	210	---
Weight Gain (g)	--	31	43	47	40	161
DBPP, 100 ppm						
Body Weight (g)	49	74	115	159	199	---
Weight Gain (g)	--	25	41	44	40	150
DBPP, 1000 ppm						
Body Weight (g)	50	72	104	144	172	---
Weight Gain (g)	--	22	32	40	28	128

Table 48. Body weight of Rats Treated with Tris(2,3-dibromopropyl) Phosphate and Followed by a Recovery Period (Kerst, 1974)

Average Individual Weekly

Sample Description	Weeks						
	0	1	2	3	4	5*	6*
Negative Control	51	72	124	153	191	221	252
DBPP, 100 ppm	51	50	107	148	168	210	247
DBPP, 1000 ppm	51	60	100	132	156	188	236

* Post treatment weeks - animals on unsupplemented basal ration.

The reduced body weight gains on DBPP-treated rats may have been due to decreased feed consumption as indicated in Table 49.

Table 49. Feed Consumption (Kerst, 1974)

Average Individual-Weekly

Sample Description	Test Period Feed Consumption (2)				
	1 Week	2 Week	3 Week	4 Week	Total
Negative Control	76	108	135	140	459
DBPP, 100 ppm	75	108	132	137	453
DBPP, 1000 ppm	61	100	122	120	403

Sample Description	Withdrawal Feed Consumption (g)						
	1 Wk.	2 Wk.	3 Wk.	4 Wk.	5 Wk.	6 Wk.	Total
Negative Control	167	164	164	154	165	182	996
DBPP, 100 ppm	158	138	138	154	152	176	916
DBPP, 1000 ppm	150	143	169	148	156	188	954

In addition, a slightly poorer feed conversion efficiency (grams feed consumed/grams body weight gain) in treated rats may reflect a toxic action of DBPP and may have contributed to the reduced rate of weight gain (Table 50).

Table 50. Feed Efficiency* (Kerst, 1974)

Average Individual-Weekly

Sample Description	Feed Efficiency (ratio)				
	1 Week	2 Week	3 Week	4 Week	4 Week Cumulative
Negative Control	2.5	2.5	2.9	3.5	2.9
TBPP, 100 ppm	3.0	2.6	3.0	3.4	3.0
TBPP, 1000 ppm	2.8	3.1	3.1	4.3	3.3

*$\frac{\text{Grams Feed Consumed}}{\text{Grams Gained}}$

Detailed data from hematologic, blood chemistry and urine analyses in treated and untreated control animals indicated that no changes could be attributed to the DBPP treatment. The parameters which were measured included determinations of red blood cells, white blood cells, hemoglobin, packed cell volume, serum glutamic oxalacetic transaminase and blood urea nitrogen; urinary measurements were made for excreted blood, bilirubin, ketones, glucose, albumin, and pH.

A further examination of organ weight data conducted by Kerst (1974) demonstrated that both mean organ weight and organ weight expressed as percent of body weight were reduced in DBPP-treated rats (Table 51).

in the absence of accompanying clinical evidence of intoxication, it was assumed that differences in organ weights between treated animals and controls were due to decreased food consumption resulting in a poor nutritional state.

Table 51. Organ Weights and Organ Weights Expressed as Percent of Body Weight*
(Kerst, 1974)

Average Values (g)

Body Weight	Heart	Liver	Spleen	Kidney	Gonads
			Negative Control		
205	1.191 (0.582)	11.60 (5.64)	0.907 (0.442)	2.513 (1.22)	2.808 (1.37)
			DBPP, 100 ppm		
200	0.945 (0.473)	10.33 (5.18)	0.702 (0.351)	2.234 (1.12)	2.385 (1.19)
			DBPP, 1000 ppm		
173	0.856 (0.459)	8.54 (4.93)	0.608 (0.355)	1.731 (0.99)	1.911 (1.09)

* Organ weights expressed as percent of body weights are in parentheses.

Histopathologic examination of various organs revealed minor lesions of the liver and kidneys (cloudy swelling and nephrosis) which could be demonstrated in both treated and control animals, and therefore were assumed to be spontaneous.

ii. Dichlorvos

Several subacute and chronic toxicity studies have been conducted in rats by oral exposures to dichlorvos for periods of up to two years (Durham et al., 1957; Witherup et al., 1971; Tracy et al., 1960). These studies have revealed that the primary effect of long-term treatment is a transient depression of cholinesterase activities. Histopathological examinations have demonstrated no adverse effects on body organs. Similar results were obtained in studies with dogs (Witherup _et al_., 1971) and monkeys (Hass _et al_., 1972).

Subacute and chronic studies on dichlorvos indicated that skin irritation and variations in cholinesterase activity levels have resulted from dermal exposures in some species, primarily cats and dogs (Smith, 1968; Schnelle, 1969; Fox _et al_., 1969a,b; Elsea _et al_., 1970; Cronce and Alden, 1968; Ritter _et al_., 1970). A monkey was reported to have died from ten daily dermal doses of dichlorvos at 75 mg/kg of body weight (Durham _et al_., 1957).

Rats and monkeys chronically exposed to dichlorvos vapors at levels as high as 5 mg/l have developed only transitory depression of cholinesterase activities (Blair _et al_., 1975; Dix, 1975; Durham _et al_., 1957; Witter _et al_., 1961).

iii. Naled

Both Standard Oil Co. (1964) and Chevron Chemical Co. (1970) have reported no adverse effects in rats resulted from feeding a dietary regimen containing naled. Sósnierz _et al_. (1971) indicated that alkaline and acid phosphatase enzyme activities in the liver of rats were disrupted by administering 90 oral doses of naled at 0.675 or 2.025 mg/kg of body weight.

Subacute exposures to 42 μg/l of a naled aerosol resulted in decreased cholinesterase activity levels in rats along with symptoms of inactivity and obvious discomfort (Standard Oil Co., 1964).

c. Sensitization

Studies on the sensitization of humans by exposure to the haloalkyl phosphates have been presented in Section III-B-2-b (p. 112) of this report. Sensitization in animals has not been demonstrated for either dichlorvos or naled.

Morrow and coworkers (1975) attempted to sensitize guinea pigs to DBPP. Attempts to enhance the sensitization reaction were made by injection (intraperitoneal) with Freund's Complete Adjuvant or intradermal injection of DBPP mixed with methylene bis(4-cyclohexyl isocyanate). Five attempts to sensitize guinea pigs (five to ten animals per group) were all unsuccessful.

d. Teratogenicity

i. Tris(haloalkyl) phosphates

A search of the scientific literature has not revealed any reports where the tris(haloalkyl) phosphates may have been tested for teratogenic activity or other effects on reproduction.

ii. Dichlorvos

Several studies in rats and swine exposed to dichlorvos in the diet or by inhalation have failed to reveal any significant teratogenic effects (Kimbrough and Gaines, 1968; Witherup *et al*., 1971; Thorpe *et al*., 1972; Collins *et al*., 1971). Minimal teratogenic effects were noted in the offspring of rabbits exposed to dichlorvos vapors at 4 μg/ℓ throughout the period of pregnancy (Thorpe *et al*., 1972).

Teratogenicity studies have also been conducted with dichlorvos using fertile chicken and duck eggs. Injection of fertile eggs with dichlorvos produced toxic reactions leading to death, but no significant incidence of deformities in the hatching birds (Dunachie and Fletcher, 1969; Khera and Lyon, 1968; Proctor and Casida, 1975).

iii. Naled

Proctor and Casida (1975) included naled among the insecticides which they tested for teratogenicity and effects on nicotinamide adenine dinucleotide activity in chick embryos. Although specific data were not given, naled was reported to be among the substances having the least teratogenic action of those tested.

e. Mutagenicity

Biological alkylations caused by foreign substances can alter the chemical structure of cellular DNA and produce a mutagenic response. Many of the organophosphates, including dichlorvos and naled, are effective alkylating agents (See Section III-B-1-c-ii, p. 108) and therefore highly suspect as potential mutagens.

i. Tris(haloalkyl) Phosphates

Preliminary results of studies conducted with commercial preparations of DBPP have indicated that mutagenesis can be induced in certain bacterial strains (Prival, 1975). Histidine-deficient strains of Salmonella typhimurium were employed in disc plate assays with DBPP, and in the plate incorporation assay, as developed by Ames. Using the Ames assay system, DBPP was tested in the presence and absence of an activating system prepared from extracts of rat liver. In certain cases, extracts were prepared from the liver of rats whose microsomal enzymes had been induced by the administration of polychlorinated biphenyls.

Results from the disc plate assay indicated that 97% pure DBPP was mutagenic to strains of Salmonella typhimurium which detected chemicals causing base pair substitution mutations, but not to strains which detected frame shift mutagens.

In the plate incorporation assay, eight different commercial preparations of DBPP were found to be mutagenic, but only to the bacterial strains which detected agents causing base pair substitutions. Mutagenesis was expressed both in the presence and absence of a metabolic activation system, although activation enhanced the mutagenic response. The activation system from induced rat liver produced greater mutagenic activity than extracts from uninduced liver. Plate incorporation tests were conducted three times, each by a different technician, and the test results were confirmed in every instance.

When CEP and DCPP were tested in the Ames plate incorporation assay as described above, the results were negative in the bacterial strain which detected base pair substitution mutagens.

Further tests are being conducted with DBPP using two strains of Escherichia coli (a DNA polymerase-deficient strain and a tryptophan-deficient strain), and in a tryptophan and adenine-requiring strain of Saccharomyces cerevisiae. In addition, scientists at the National Institute of Environmental Health Sciences will repeat the plate incorporation assays of DBPP with Salmonella typhimurium and also test the compound in a forward mutational system in E. coli and in Neurospora crassa.

Positive mutagenic data, such as that reported with DBPP, is significant not only in its implication for identifying potential reproductive hazards, but also in predicting carcinogenicity. Kriek (1974) has stated that all carcinogens are mutagenic (but not necessarily vice versa). Furthermore, the International Agency for Research on Cancer now includes mutagenicity data in its monographs on the evaluation of the carcinogenic risk of chemicals to humans.

ii. Dichlorvos

The majority of the mutagenicity studies using dichlorvos have been conducted with deficient bacterial strains. Several techniques, agar plates, paper disc, nutrient broth suspension, and host-mediated assay, have been utilized. Dichlorvos caused increases in reverse mutations in strains of Salmonella typhimurium (Dyer and Hanna, 1973; Voogd et al., 1972), Pseudomonas aeruginosa (Dyer and Hanna, 1973), Klebsiella pneumoniae (Voogd et al., 1972), Citrobacter freundii (Voogd et al., 1972), Enterobacter aerogenes (Voogd et al., 1972), Serratia *marescens* (Dean *et al.*, 1972), and *Escherichia coli* (Voogd *et al.*, 1972; Bridges *et al.*, 1973; Wild, 1973; Löfroth *et al*, 1969; Ashwood-Smith *et al.*, 1972). In bacterial assay systems, dichlorvos was reported by several investigators to be a much weaker mutagen than methyl methanesulfonate (Bridges *et al.*, 1973; Lawley *et al.*, 1974). It was observed that dichlorvos methylates cellular proteins more readily than it methylates nucleic acids (Lawley *et al.*, 1974).

In a host-mediated assay in mice, dichlorvos failed to induce reverse mutations in *Saccharomyces cerevisiae* (Dean *et al.*, 1972). The authors suggested that the extremely rapid *in vivo* metabolism of dichlorvos prevented the induction of mutagenesis.

Cytogenetic studies in mice and Chinese hamsters exposed to acute doses of dichlorvos by ingestion or inhalation failed to reveal significant chromosome damage (Dean and Thorpe, 1972a). Studies in which mice were chronically exposed to dichlorvos produced similar negative results (Dean and Thorpe, 1972b).

iii. Naled

No direct information on the possible mutagenicity of naled has been encountered. The alkylating abilities of this chemical and the fact that it is metabolized to dichlorvos might make it suspect as a possible mutagen.

f. Carcinogenicity

To some extent, all organophosphates can act as alkylating agents. The alkylating abilities of the haloalkyl phosphates are discussed in Section I-B-2 (p. 18) and the biological significance of alkylation is presented in Section III-B-1-c-ii (p. 108). With respect to carcinogenicity, it is well-recognized that spontaneous alkylations of biologically-important molecules, particularly DNA, can lead to tumor formation (Bedford and Robinson, 1972; Rosenkranz, 1973). Furthermore, the positive correlation between carcinogens and mutagens (Kriek, 1974) is of considerable interest in light of recent evidence indicating that DBPP and dichlorvos can display mutagenic activity.

i. Tris(haloalkyl) Phosphates

Information on the potential carcinogenicity of the tris(haloalkyl) phosphates is not presently available. However, the National Cancer Institute initiated carcinogenicity tests in March, 1974 on rats and mice exposed orally to DBPP (Prival, 1975). These studies are not yet completed; animals are due to be sacrificed in the Spring of 1976.

The key to whether or not DBPP is carcinogenic may well be the rate at which it is metabolized in vivo to form non-alkylating products. It has already been recognized that the chemical hydrolysis of the tris(haloalkyl) phosphates does not occur as rapidly as for dichlorvos (See Section I-B-2, p. 18). If the tris(haloalkyl) phosphates can remain intact within the body for a sufficient period to allow for biological alkylations to occur at the subcellular level, a carcinogenic response may be predicted.

ii. Dichlorvos

Specific data have not been encountered on the potential carcinogenicity of dichlorvos. One study (Preussmann, 1968) has shown, however, that trichlorphon (0,0-dimethyl-1-1-hydroxy-2,2,2-trichloroethyl phosphonate), which is metabolized through dichlorvos, produced sarcomas in two of 24 rats when injected subcutaneously once weekly with the substance.

iii. Naled

No data have been encountered on the carcinogenicity of naled.

g. Possible Synergisms

No data are available on possible synergisms of chemical substances with the haloalkyl phosphates. As components of fabrics, however, it might reasonably be expected that the fire retardant tris(haloalkyl) phosphates would contact a number of compounds through normal use (e.g., dyes, laundering agents) and in various hypothetical situations (e.g., spillage of chemicals on a person's clothing).

The insecticides, dichlorvos and naled, are frequently mixed with other agricultural chemicals prior to application. Therefore, considerable opportunity for synergistic action does occur.

4. Effects on Other Vertebrates

a. Birds

Avian toxicity studies involving the haloalkyl phosphates have been limited almost exclusively to experimentation with dichlorvos. Chevron Chemical Co. (1970), however, reported that naled, when applied at recommended rates, did not cause any mortality in several species of birds: quail, pheasant, duck, and others including shore birds and aquatic birds. Most of the available data on dichlorvos is derived from studies in chickens, although LD_{50} data on two species of wild birds have also been reported (Table 52).

b. Fish

The toxicity of the haloalkyl phosphates has been studied in numerous species of fresh and salt water fish. The methodologies for testing in fish range from continuous exposure over several days to a brief exposure in

Table 52. Acute Toxicity of Dichlorvos to Birds

Bird	Breed, No. Sex, Age, Weight	Route	Vehicle	LD_{50} in mg/kg	Comments	Reference
Redwing Blackbird *Agelarius phoenicus*		Oral, via gavage	In propylene glycol	17		Schafer, 1972
Starling *Sturnus vulgaris*		Oral, via gavage	In propylene glycol	12		Schafer, 1972
Chicken	18 (total) Rhode Island Red, hens, 2.5-4.0 kg	Subcutaneous injection	In peanut oil @ 1 ml/kg body weight	20	7-day observation period; death occurred in 1 day (average)	Durham *et al.*, 1956
Chicken	5-30 @ each dose level, New Hampshire chicks, 7-14 days old	Oral	In gelatin capsule	14.8	19/20 confidence limits 13.1 to 16.7; 7-day observation, death in 24 hours	Sherman and Ross, 1961

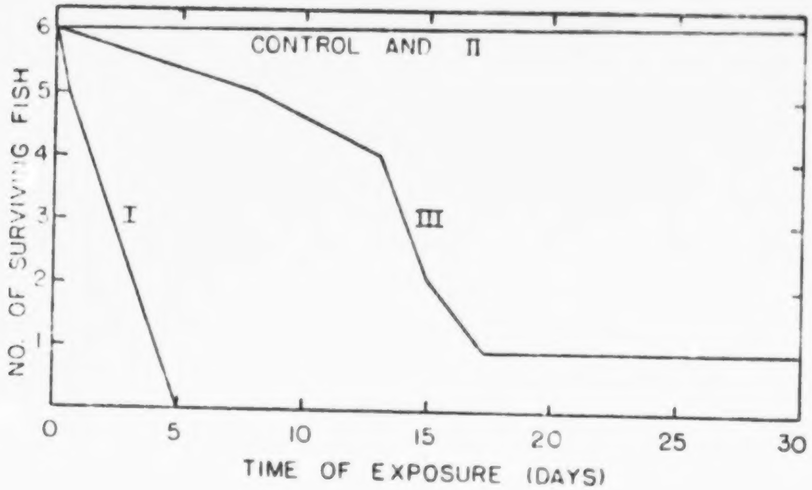
minutes or hours. Data are often given as lethal tolerance (TL) or lethal concentration (LC) figures.

i. Tris(haloalkyl) Phosphates

Gutenmann and Lisk (1975) evaluated the toxicity of DBPP to goldfish after determining that the chemical could be leached from fire retardant-treated fabrics in a simulated laundering operation. A polyester flannel fabric treated with DBPP was found to release up to 10 μg per square inch of fabric into the laundry water. The authors exposed goldfish to a concentration of 1 ppm of DBPP in water, based on the assumption that a typical home laundering may involve the washing of six sheets, each 72 x 81 inches, which could result in a concentration of 6 ppm of DBPP in 30 gallons of combined wash and rinse water.

Six goldfish were placed in a tank with 20 liters of aerated water and exposed to four ml of a solution containing 5 mg/ml of DBPP in acetone (final concentration = 1 ppm DBPP). Control fish were exposed to acetone only. Data on fish survival after exposure to DBPP and two other organophosphorus fire retardants are presented in Figure 10. All of the goldfish exposed to DBPP died within five days. The fish were observed to swim in a completely-disoriented manner prior to death. Death may have been due to cholinesterase inhibition, but DBPP had less anticholinesterase activity than THPOH [tetrakis (hydroxymethyl)phosphonium hydroxide] (DBPP and THPOH had 16% and 25%, respectively, of the activity of Tetram). However, the authors suggested that the greater lipid solubility of DBPP may have enhanced absorption and thereby produced a greater toxic effect, in spite of its lower anticholinesterase activity.

Figure 10. Survival of Goldfish Exposed to 1 ppm of Flame Retardant Compounds (Gutenmann and Lisk, 1975)



I. tris(2,3-dibromopropyl) phosphate (DBPP)
II. Pyrovatex CP
(N-methylol dimethyl phosphonopropionamide)
III. THPOH
tetrakis(hydroxymethyl) phosphonium hydroxide

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ii. Dichlorvos

Data on the toxicity of dichlorvos to fish are summarized in Table 53. In some cases the TL_{50} or LC_{50} (concentration to cause death in 50% of the population) is less after 96 hours than after 24 hours of exposure, which indicates a cumulative toxicologic effect.

iii. Naled

A summary of the available data on the toxicity of naled to fish is also presented in Table 53.

Table 53. Fish Toxicity of Dichlorvos and Naled

Compound	Species, #, sex, length, weight	Exposure conditions	Exposure period	Concentration	Remarks	References
Dichlorvos (0,0-dimethyl 2,2-dichlorovinyl phosphate)	rainbow trout *Salmo gairdneri*		up to 72 hrs	1 ppm	no apparent harmful effects in 72 hrs	Lewallen and Wilder, 1962
				10 ppm	all dead in 24 hrs	
	sheepshead minnows, *Cyprinodon variegatus* 5M & 5F in each test	temperature: 21 ± 2°C pH: 7 ± 0.2	15 min to 120 hrs		caused drop in brain acetylcholinesterase activity to < 17.7% of control value	Coppage, 1972
	mummichogs, *Fundulus heteroclitus*	varied temperature and salinity	96 hrs	3700 ppb	LC$_{50}$; generally increasing temperature or salinity; LC$_{50}$ at 240 hours = 3160 ppb	Eisler, 1970a
	several estuarine teleost species	temperature: 20°C salinity 24‰ pH: 8.0	96 hrs	225 to 2680 ppb	LC$_{50}$ range for all species tested; see text for details	Eisler, 1970b
	fathead minnows, *Pimephales promelas*, 38 to 64mm, 1 to 2 gr., 10 at ea. conc., 10 control	95% dichlorvos in acetone -- in "soft" water, at 25°C	24 hrs		no tolerance limit found	Pickering and Henderson, 1966
			48 hrs	7.9 ppm (6.2 to 10.0)	TL$_m$ (median tolerance limit) with 95% confidence limits	
			96 hrs	4.0 ppm (3.2 to 5.0)	TL$_m$, with 95% confidence limits	

Table 53. (cont'd)

bluegills, *Lepomis macrochirus*, 35 to 64mm, 1 to 2 gr., 10 at ea. conc. + 10 control	95% dichlorvos in acetone -- in "soft" water at	24 hrs		no tolerance limit found	Pickering and Henderson, 1966
		48 hrs	0.32 ppm (.24 to .40)	TL_m, with 95% confidence limits	
		96 hrs	0.27 ppm (.22 to .35)	TL_m, with 95% confidence limits	
bluegills, *Lepomis macrochirus* (as above)	95% dichlorvos in acetone, in "hard" water, 25°C	24 hrs	.87 ppm (.67 to 1.8)	TL_m, with 95% confidence limits	Pickering and Henderson, 1966
		48 hrs	.46 ppm (.36 to .58)	TL_m, with 95% confidence limits	
		96 hrs	.35 ppm (.27 to .44)	TL_m, with 95% confidence limits	
bluegills, 0.87g	technical grade dichlorvos at 75°C	24 hrs	1 ppm	estimated LC_{50}	Cope, 1965
		48 hrs	0.7 ppm	estimated LC_{50}	
		96 hrs	0.48 ppm	estimated LC_{50}	
Cyprinus carpio (Bangkok str.) 2.5-6.0 cm	28.5-28.8°C pH 7.2	48 hrs	15.0 ppm	TL_m	Sreenivasan and Swaminathan, 1967
			22.5 ppm	LC_{100}	
Cyprinus carpio (German) 2.5-6.0 cm	same as above	48 hrs	5.5 ppm	TL_m	Sreenivasan and Swaminathan, 1967
			9.5 ppm	LC_{100}	
Tilapia mossambica 2.5-6.0 cm	same as above	48 hrs	3.0 ppm	TL_m	Sreenivasan and Swaminathan, 1967
			6.0 ppm	LC_{100}	

Table 53. (cont'd)

Cirrhira mrigala 1.0-2.0 cm	same as above	48 hrs	25.0-30.0 ppm 35.0-40.0 ppm	TL_m LC_{100}	Sreenivasan and Swaminathan, 1967
Labeo fimbriatus 1.0-2.9 cm	same as above	48 hrs	18.0 ppm 37.5 ppm	TL_m LC_{100}	Sreenivasan and Swaminathan, 1967
Trichogaster fasciatus young, 15, 38-45 mm		168 hrs	3 ppm	LD_{100}	Srivastava and Konar, 1966
adults, 14, 86-112 mm			5 ppm	LD_{100}	
Channa punctatus fingerlings, 15, 36-50 mm		168 hrs	3 ppm	LD_{100}	Srivastava and Konar, 1966
adults, 14, 86-112 mm			5 ppm	LD_{100}	
Mastocembelus pancalus, 9 53-78 mm		168 hrs	5 ppm	LD_{100}	Srivastava and Konar, 1966
Macrognathus aculeatum, 10, 149-180 mm		168 hrs	5 ppm	LD_{100}	Srivastava and Konar, 1966
Nandus nandus, 9, 76-85 mm		168 hrs	5 ppm	LD_{100}	Srivastava and Konar, 1966
Rita rita, 10, 119-125 mm		168 hrs	5 ppm	LD_{100}	Srivastava and Konar, 1966
Amphipnous cuchia, 12, 168-453 mm		168 hrs	5 ppm	LD_{100}	Srivastava and Konar, 1966
Mystus vittatus, 15, 74-81 mm		168 hrs	10 ppm	LD_{100}	Srivastava and Konar, 1966
Puntius sophore, 15, 40-45 mm		168 hrs	10 ppm	LD_{100}	Srivastava and Konar, 1966
Esomus danrica, 15, 40-51 mm		168 hrs	30 ppm	LD_{100}	Srivastava and Konar, 1966
Labeo rohita late fingerlings, [illegible] [illegible] mm		168 hr	30 ppm	[illegible]	Srivastava and Konar, 1966

Table 53. (cont'd)

Naled [O,O-dimethyl-O-(1,2-dibromo-2,2-dichloroethyl)phosphate]	rainbow trout *Salmo gairdneri*		up to 72 hrs	1 ppm	death occurred in 48 hrs, survivors appeared normal at 72 hrs	Lewallen and Wilder, 1962
				10 ppm	all dead by 24 hrs	
	rainbow trout *Salmo gairdneri*	temperature: 12.7°C pH: 7.1	24 hrs	240 (210-270) ppb	TL_{50} with confidence limits	Macek et *al*., 1969
			96 hrs	160 (150-170) ppb	TL_{50} with confidence limits	
	rainbow trout			0.08 ppm	LC_{50}	Chevron Chemical Company, 1970
	mosquito fish *Gambusia affinis*			levels used to kill larvicidal mosquitos	moderately toxic	Mulla et *al*., 1963
	Gambusia			0.5 lb/acre	no mortality	Chevron Chemical Company, 1970
	goldfish			2-4 ppm	LC_{50}	Chevron Chemical Company, 1970
	guppy			1-2 ppm	LC_{50}	Chevron Chemical Company, 1970

Table 53. (cont'd)

bluegill			[illegible] ppm	[illegible]	Chevron Chemical Company, 1970
bluegill	technical grade naled at [illegible]	24 hrs	[illegible] ppm	estimated LC50	Cope, 1965
		48 hrs	[illegible] ppm	estimated LC50	
		96 hrs	[illegible] ppm	estimated LC50	
largemouth bass			[illegible] ppm	LC50	Chevron Chemical Company, 1970
red crawfish, *Procambarus clarki*, 4-10g, 64 total	technical grade naled, pH 7.5, alkalinity 8 ppm, 16-32°C temperature	24 hrs	[illegible] ppm	TL_m	Muncy and Oliver, 1963
		48 hrs	[illegible] ppm	same as above	
		72 hrs	[illegible] ppm	same as above	
sheepshead minnows, *Cyprinodon variegatus* 5M & 5F in ea. test	temperature: 21 ± 2°C pH: 7 ± 0.2	15 min to 120 hrs		caused drop in brain acetylcholinesterase activity to ≈ 17.7% of control value	Coppage, 1972
spot		24 hrs	75 ppb (theoretical)	reduced brain acetylcholinesterase by 85 (82-89)%	Coppage and Matthews, 1974
pinfish, *Lagodon rhomboides* groups of 4		72 hrs	15 ppm nominal	65% less brain acetylcholinesterase activity than controls; no deaths	Coppage and Matthews, 1975
		72 hrs	25 ppm nominal	89% less brain acetylcholinesterase activity than controls; 40-60% mortality	

5. Effects on Invertebrates

a. Insects

No information is available on the toxic effects of the fire-retardant haloalkyl phosphates to invertebrates. The toxicity of dichlorvos and naled to various insects has been studied in detail. On topical application to various insects, LD_{50} values of dichlorvos range from 0.694-18.0 μg/g (Aziz, 1973; Drake et al., 1971; Hutacharern and Knowles, 1974; Keiser et al., 1973; Metcalf et al., 1959; Van Asperen, 1958a; Yates and Sherman, 1970). Comparable values for naled range from 0.483-124 μg/g (Chalfant, 1973; Drake et al., 1971; Keiser et al., 1973; Lyon et al., 1972; Yates and Sherman, 1970).

Esterase inhibition is commonly regarded as the primary toxic effect of dichlorvos and naled to insects (Heath, 1961; Hutacharern and Knowles, 1974; Tripathi and O'Brian, 1973; Van Asperen, 1958a and b). The known secondary effects of these compounds seem to be related primarily to decreased fecundity (Kreasky and Mazuranich, 1971; Zettler and LeCato, 1974). Both hydrolysis and demethylation, common features in the mammalian metabolism of both compounds, have been demonstrated in insects (Krueger and Casida, 1961; Miyata and Matsumura, 1972).

b. Other Invertebrates

The 48 hour EC_{50} for immobilization of two cladocerans species using both dichlorvos and naled are given in Table 54.

Tripp (1974) has studied the effects of naled on mortality and reproduction in oysters (Crassotrea virginica). Gross toxic response was determined by immersing groups of oysters in 1 ppm and 10 ppm naled solutions for 24 hours, twice weekly, for approximately four months. Only at the higher concentration was mortality markedly increased (25.2%) above control levels

Table 54. Estimated 48-Hour EC_{50} Immobilization Values in μg/g for Two Species of Daphnids Exposed to Dichlorvos and Naled at 60°F and 70°F. (Sanders and Cope, 1966)

Toxicant	*Simocephalus serrulatus*		*Daphnia pulex*
	60°F	70°F	60°F
Dichlorvos	0.26 (0.16-0.42)[a]	0.28 (0.16-0.47)	0.066 (0.049-0.088)
Naled	1.1 (1.0-1.3)	1.1 (0.80-1.4)	0.35 (0.22-0.78)

[a] Figures in parentheses are confidence limits for $P = 0.05$.

(8.3%). No histological damage attributable to naled was found in 153 treated oysters. Based upon combination of field and laboratory exposures, Tripp (1974) has concluded that chronic exposure to 10 ppm naled does not significantly affect oyster reproduction.

6. Effects on Plants

Due to the insecticidal use of two of the haloalkyl phosphates, dichlorvos and naled, considerable exposure to plants does occur. Evidence presented in mutagenicity studies using dichlorvos on the broad bean root cells and on onion root tip cells indicated some chromosomal effects (Löfroth et al., 1969; Sax and Sax, 1968). Product information on dichlorvos (Shell Chemical Co., 1973) reported no phytotoxicity in a wide variety of plants under normal application conditions. Chevron Chemical Co. (undated b) product labels on naled (Dibrom®) indicate that overtreatment of pests may lead to the injury of plants. Naled vapors may injure certain roses, chrysanthemums, wandering jews, poinsettias, and Dutchman's pipe. An additional warning is made to avoid spraying nectarines, ornamental cherries, liquidambar, or chrysanthemums (Chevron Chemical Co., undated b).

No information on the potential phytotoxicity of the tris(haloalkyl) phosphates is available.

7. Effects on Microorganisms

Some of the haloalkyl phosphates have been tested for mutagenic effects in various microorganisms (See Section III-B-3-e, p. 139). The results of this work indicated toxic effects and some increase in chromosome aberrations occurring in microorganisms treated with dichlorvos or tris(2,3-dibromopropyl) phosphate.

Dougherty and coworkers (1971) studied the effects of various concentrations of naled and dichlorvos on Bacillus thuringiensis. Agar plates were innoculated with bacterial spores. Each dilution of insecticide solution was applied to a paper disc which was placed on the agar plate. After a 24-hour incubation at 31°C, the presence or absence of an inhibition zone (1 mm minimum) was recorded. Dichlorvos failed to inhibit growth at any concentration tested, but naled caused significant inhibition at a molar concentration of 10^{-5} in benzene or Tween 80, and at 10^{-3} in dimethyl sulfoxide. Dougherty and coworkers (1971) indicated that the apparent difference in effect was probably due to the relative solubility of naled in each solvent.

Naled was found to be fairly toxic to bacterial populations in waste disposal lagoons by Steelman and coworkers (1967). The lagoons are utilized for disposal of livestock and poultry wastes. Due to the nature of the materials in the lagoon, mosquitoes find the area an excellent breeding site. Naled, a mosquito larvicide, was tested for its effect on the microbial population which is essential for waste degradation. Lagoon water (3000 ml) was mixed with each of five concentrations (0.0001, 0.1, 0.5, 1.0, and 5.0%) of naled. Bacterial tests were made at 24 hours and, at the lowest concentration, colony counts were determined after 24 and 48 hours of continuous exposure. Their data showed an increase in mortality with increase in naled concentration in the closed laboratory situation. Steelman and co-workers (1967) noted that in operating lagoons, the addition of water to wash fecal material would tend to dilute the naled concentration and, thereby, presumably reduce bacterial mortality. These investigators felt that the level of bacterial mortality at 1 ppm naled would not disrupt the lagoon function.

8. Biochemical Studies

a. Effects on Cell Cultures

Dean (1972) determined the effects of dichlorvos on cultured human lymphocytes by addition of the chemical at various stages of development. He observed chromosome degeneration in certain cases, which was different than the chromosome pulverization caused by high concentrations of alkylating agents. Dean (1972) concluded that dichlorvos was cytotoxic to cultured lymphocytes at concentrations up to 40 μg/ml, but probably did not affect chromosomes by direct alkylation of DNA.

b. Effects on Nucleic Acids and Protein

The known alkylating effects of the haloalkyl phosphates has led to considerable discussion regarding their possible effects on nucleic acids, including RNA and DNA. Biological alkylations are often manifested as mutations, and the mutagenic properties of several haloalkyl phosphates are discussed in Section III-B-3-e (p.139).

A few studies have examined the actions of dichlorvos on isolated DNA. Löfroth et al. (1969) demonstrated that dichlorvos can cause a 1% conversion of guanine to N-7-methylguanine in calf thymus DNA. Rosenkranz and Rosenkranz (1972) obtained decreases in the sedimentation coefficient of DNA after exposure to dichlorvos. This change was presumably due to alkylation followed by depurination. In addition, further changes were noted along the single strands from denatured DNA.

IV. Regulations and Standards

A. Current Regulations

The haloalkyl phosphate pesticides are heavily regulated by Federal law. However, in contrast, the fire retardants have few restrictions placed upon their commercial use. There are a number of Federal and state regulations that apply to fire retarded products, but these are fire retardant standards of the product and do not apply to any chemical additive in particular.

1. Food, Drug, Pesticide Authorities

Billings (1974) outlined the current system of Federal pesticide regulation. The Federal laws primarily concerned with pesticides are the Federal Environmental Pesticide Control Act (FEPCA) of 1972 (PL92-516), which adds authority to the Federal Insecticide, Fungicide, Rodenticide Act (FIFRA) of 1947 and the Federal Food, Drug and Cosmetic Act of 1938, which was revised to include pesticides ("economic poisons") in 1954.

The established tolerances for food residues for dichlorvos and naled vary from 10 ppm to 0.02 ppm depending upon the food crop being considered (EPA, 1971, 1972a,b,c, 1974, 1975a, b). Tolerances for dichlorvos often include "expressed as naled" and naled tolerances also include "its conversion product 2,2-dichlorovinyl dimethyl phosphate."

Dichlorvos is regulated by other sections of the Food, Drug and Cosmetic Law, both as a food additive and as an animal drug. A level of 0.5 ppm dichlorvos was permitted by the FDA (1968) as a food additive residue from application as an insecticide on packaged or bagged nonperishable processed food. The FDA (1975c) has established a tolerance of 0.1 ppm for negligible residues of dichlorvos in the edible tissues of swine.

Dichlorvos is regulated as a new animal drug under the Federal Food, Drug and Cosmetic Act. The FDA (1975a) has general regulations concerning adequate labeling of anthelmintic drugs and directions. In addition, specific regulations for the anthelmintic use of dichlorvos on swine are given.

The FDA (1965) approved the prescription use of dichlorvos in oral pellet form (Atgard V) as an anthelmintic in swine. The Federal Food, Drug and Cosmetic Act has established a 9.6% level of dichlorvos which may be mixed in feed for swine (FDA, 1970) and the maximum dosage levels which can be administered (FDA, 1971). These regulations were amended most recently in the fall of 1975 (FDA, 1975b).

2. Air and Water Acts

The Federal Water Pollution Control Act (1970) and Amendments (1972) regulate the presence of pollutants, including pesticides, in water and waterways. Both dichlorvos and naled are included in this list of hazardous substances. Dichlorvos is listed under the EPA category "A" which denotes an LC_{50} <1 ppm for aquatic animals over an exposure period of 96 hours or less. The harmful quantity (HQ) in pounds (kg) is 1.0 (0.454). Naled is also listed in category A with the same HQ.

3. OSHA

The Occupational Safety and Health Administration provides an exposure standard for dichlorvos of 1 mg/m^3 (OSHA, 1974). In addition, OSHA provides general regulations on personal protective equipment for workers in pesticide industry (Billings, 1974).

4. Transport Regulations

The Department of Transportation (DOT) regulates interstate and foreign transport of goods. The pesticides are regulated by the Hazardous Regulation Board. Most pesticides are considered Class "B" poisons (Billings, 1974). According to Shell Chemical Co. (1973a), Vapona insecticide (dichlorvos) does not require a Class B Poison label and is thereby exempt from DOT packaging restrictions.

5. Consumer Product Safety Commission (CPSC)

On March 24, 1976, the Environmental Defense Fund (EDF) petitioned the CPSC concerning the use of DBPP as a fire retardant in sleepwear for children less than 12 years old. EDF asked that CPSC require that labels on sleepwear indicate that the material be washed three times before use. Also, EDF requested that a scientific inquiry be initiated for considering a ban on sleepwear use of DBPP. The petition was based upon (1) the mutagen effects of DBPP in the Ames bacterial assay system, (2) migration studies by St. John et al. (1976), and (3) the studies of Morrow et al. (1975), who demonstrated that almost all of the DBPP lost (12%) occurred during the first three washings.

B. Concensus and Similar Standards

1. TLV

The American Conference of Governmental Industrial Hygienists has established Threshold Limit Values (TLV's) in workroom air for the two pesticides, dichlorvos and naled (ACGIH, 1974). The dichlorvos regulations (skin) are 0.1 ppm and 1 mg/m^3. For naled a limit of 3 mg/m^3 has been established.

No TLV's have been established for the flame retardant haloalkyl phosphates.

2. Public Exposure Limits

The Food and Agriculture Organization (FAO) of the United Nations and the World Health Organization (WHO) recommended a maximum acceptable daily intake of dichlorvos at 0.004 mg/kg body weight (FAO/WHO, 1967).

3. Other

Capizzi and Robinson (1973) have estimated the relative acute toxic hazard of 85 pesticides to applicators. The chemicals are divided into four groups, ranging from "most dangerous" to least dangerous." Dichlorvos is placed in the "dangerous" group (the second most toxic) and naled in the "less dangerous" category.

Sasinovich (1968) recommended a maximum permissible concentration (mpc) for dichlorvos in workroom air at 0.2 mg/m^3 for the USSR.

V. Summary and Conclusions

There are six haloalkyl phosphate (HAP) compounds that are produced in the U.S. in significant commercial quantities. Included are two pesticides, dichlorvos and naled, and four tris(haloalkyl) phosphate (tris-HAP) fire retardants: tris(2-chloroethyl) phosphate (CEP), tris(2-chloro-1-propyl) phosphate (CPP), tris(1,3-dichloro-2-propyl) phosphate (DCPP), and tris (2,3-dibromo-1-propyl) phosphate (DBPP). A new haloalkyl phosphate fire retardant, tetrakis(2-chloroethyl) ethylene diphosphate, is just beginning to reach commercial production. Emphasis in this report has been on the tris-HAP fire retardants, with data on the pesticides used for comparison purposes.

A total of approximately 30 million pounds of tris-HAP fire retardants were produced and consumed in the United States in 1974. Their growth rate is projected at over 20% annually into the 1980's. DBPP is apparently produced in the largest quantity (9-12 million pounds), while the chloroalkyl phosphates are produced in slightly smaller quantities (DCPP, 6-10 million pounds; CEP, 3-10 million pounds; and CPP, 3 million pounds).

The tris-HAP fire retardants are added to products which must meet Federal or state fire retardancy standards. While products to which the chloroalkyl phosphates are added are similar, they are substantially different from those to which DBPP is added. The chloroalkyl phosphates are used in flexible and rigid polyurethane foams (e.g., furniture, transportation, and household goods). DBPP's major application is as a fire retardant additive for cellulose acetate and polyester fibers, particularly for use in material for children's sleepwear. The low water solubility of DBPP (1.5 ppm) compared to the chloroalkyl phosphates allows for considerable fire retardancy durability for the textiles during washing.

Unlike the HAP-pesticides, the tris-HAP fire retardants are not directly released to the environment. Possible sources of release include effluents from production plants or textile and polyurethane plants, laundering of treated textiles, or leaching from materials treated with tris-HAP that have been discarded in landfills or dumps. No effluent monitoring data are available to indicate the magnitude of release from these sources; however, CEP is included on EPA's list of organic chemicals detected in drinking water and two studies have indicated that DBPP may be washed from textiles under home laundering conditions.

The stability of the tris-HAP fire retardants in the environment is unknown. The fire retardants appear to be much more resistant than the pesticides to chemical hydrolysis. One biodegradability study on DBPP was reported, but the results are difficult to interpret. The pesticide HAP's are degraded rapidly in soil, probably by biological hydrolysis.

The chloroalkyl phosphates are sufficiently water soluble to expect that they are dissolved and transported in water systems. In contrast, DBPP is very insoluble in water, and therefore, may be susceptible to some extent to absorption and bioaccumulation. This is very significant since 1 ppm DBPP in water produced 100% mortality in goldfish in five days.

The limited biological data that are available concerning the tris-HAP fire retardants do not allow for definitive conclusions to be drawn regarding their environmental hazard potential. However, two biological properties of concern become evident in view of the more extensively studied HAP insecticides.

dichlorvos and naled. These are the potential to inhibit the activity of cholinesterase enzymes and to act as alkylating agents within animal cells.

Both dichlorvos and naled are effective inhibitors, in vivo and in vitro, of cholinesterase. The primary toxic effects associated with these chemicals in acutely poisoned animals can be attributed to cholinesterase inhibition which may culminate in death at very low doses (acute oral rat LD_{50} < 100 mg/kg). Only data from studies with fish are available to indicate that DBPP exhibits definite anticholinesterase effects. The tris(haloalkyl) phosphates are much less acutely toxic than either dichlorvos or naled. The relatively reduced toxicity of the tris(haloalkyl) phosphates may be due to poor absorption, but confirming quantitative data are lacking. Humans have not been reported to be adversely affected by exposure to the tris(haloalkyl) phosphates, whereas numerous human poisonings by dichlorvos have resulted in transitory depressions of cholinesterase activity as the only consequence of exposure.

The biological implications of the alkylation of important cellular constituents, particularly DNA, point toward the induction of a carcinogenic or mutagenic response. Dichlorvos is an effective chemical alkylating agent, but no experimental information is available on the chemical alkylating ability of the tris(haloalkyl) phosphates. It is generally regarded, however, that the rapid in vivo hydrolysis of dichlorvos would prevent its acting as a potent alkylating agent in biological systems. The tris(haloalkyl) phosphates, on the other hand, are not subject to extremely rapid chemical hydrolysis, and thereby may be less susceptible to in vivo biotransformation resulting in inactivation. Experimental data are not presently available to support the conclusion that the fire retardants are resistant to rapid metabolism and excretion in mammals. Recent evidence has emerged, however, indicating that DBPP caused mutations in the Ames bacterial assay system, which strengthens the argument that the tris(haloalkyl) phosphates are potentially significant biological alkylating agents. These results warrant further investigations in higher organisms.

With respect to health effects, the pharmacokinetics and pathways of metabolism for the tris-HAP's in mammalian systems must be delineated in order to provide an accurate picture of possible chemical-biological interactions at the molecular level. Furthermore, additional data are necessary to determine whether the tris-HAP's are intrinsically potent inhibitors of cholinesterase to warrant concern with human exposure. In the final outcome, it must be established whether possible exposure levels are high enough to present a real threat to health and the environment.

The positive results of DBPP as a mutagen in bacterial systems is of particular significance because of the implications they hold for the safety of this compound when used in materials where there is direct human exposure. Notable is the fact that DBPP fire-retarded materials are used extensively for children's sleepwear, where in addition to dermal exposure, the possibility of some oral exposure resulting from chewing on the garment must be considered. The forthcoming results of the mammalian studies on DBPP will be of considerable importance in determining the human hazard potential of this compound.

The currently available information presented in this report leads to several questions for which conclusive answers are not yet available. With respect to environmental exposure, data are needed on the eventual release of the tris-HAP's from materials in which they are incorporated, and on the stability and chemical/biological breakdown products of the tris-HAP's under environmental conditions. Data are especially needed on transport into the aquatic media and the fate and effects of these compounds therein.

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